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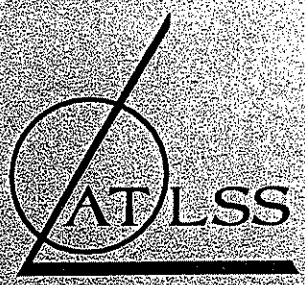


ADVANCED TECHNOLOGY FOR
LARGE
STRUCTURAL SYSTEMS

Lehigh University

1994 RESEARCH PROJECT SUMMARIES

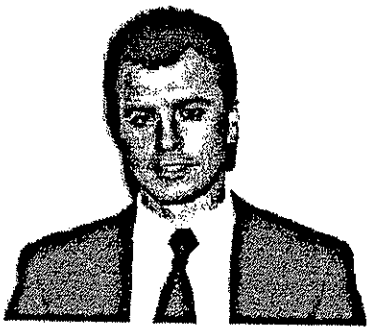
ATLSS Report No. 95-05

May 1995

An NSF Sponsored Engineering Research Center

INNOVATIVE STRUCTURAL SYSTEMS & MATERIALS

Thrust Leader



Prof. Richard Sause
(CE)
(ADC-10, ADC-14, ADC-18,ADC-E2)

Dr. Robert Dexter
(Appl. Mech.)
(ADC-E6, IFC-E7)

Prof. John Fisher
(CE)
(ADC-E2)

Dr. John H. Gross
(Matls. Sci.)
(ADC-06)

Mr. Mark Kaczinski
(CE)
(ADC-E5)

Dr. Eric Kaufmann
(Matls. Sci.)
(IFC-E10)

Prof. Celal Kostem
(CE)
(ADC-16)

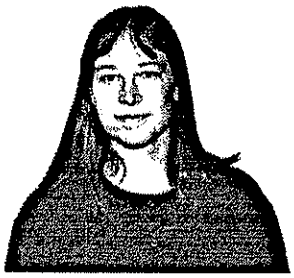
Prof. Le-Wu Lu
(CE)
(ADC-03,ADC-09,IFC-E2)

Prof. Peter Mueller
(CE)
(ADC-02)

Prof. Stephen Pessiki
(CE)
(ADC-10, ADC-17, ADC-E4)

Prof. James Ricles
(CE)
(ADC-18)

Dr. Richard Roberts
(ME)
(ADC-E6)



Prof. Sarah Slaughter
(CE)
(ADC-10, ADC-14)

Dr. Robert Stout
(Matls. Sci.)
(ADC-06)

B. Vincent Viscomi
(CE)
(ADC-03, ADC-09)

RESEARCH SUMMARY

TITLE: Unified Design Methodology and Rational Models for Precast Concrete Connections (ADC-02)
TEAM LEADER: P. Mueller (CE)
TEAM MEMBERS: J. Abruzzo (CE)

RESEARCH ISSUES ADDRESSED:

The project objectives are to develop and experimentally verify a consistent unified connection design methodology based on rational and general models; to codify this methodology; and to support the application of the ATLSS connection concept to precast concrete.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The project supports the strategic objectives of construction automation and improved performance. It provides designers with the tools to develop new connection details that are better suited for automation and show better performance (particularly seismic).

APPROACH; EXPERIMENTAL PLAN:

Precast concrete is ideally suited for construction automation. However, the lack of code provisions for connections and the ensuing lack of confidence, particularly in seismic regions, are a major impediment to the use of precast concrete. The key to codification are rational models that can be generalized to many different types of connections. Truss models meet this requirement and are currently being implemented into both ACI and AASHTO code. This project is therefore developing and experimentally verifying a library of truss models and compatible failure mechanisms for precast concrete connections. The theoretical foundation is the theory of plasticity. The project is currently in the second of three phases: (1) theoretical model development; (2) pilot experimental program; and (3) main experimental program.

RELATED WORK ELSEWHERE:

Theoretical and experimental research on truss models or strut-and-tie models is being conducted in Europe, at the University of Toronto, Canada, and at the University of Texas at Austin, USA. Truss models are already implemented in Canadian and European codes and in the 1995 editions of the ACI code for torsion and AASHTO codes for disturbed regions.

HOW ATLSS' WORK IS DIFFERENT:

While truss models are well developed for the design of beams, deep beams; corbels, and so-called disturbed regions, their application and experimental verification for precast concrete connections is in its infancy. This research is unique in that truss models are rigorously based on the theory of plasticity and associated with compatible failure mechanisms. The project interacts with other ATLSS projects in applying the ATLSS connection concept toe precast concrete (ADC-03, ADC-10).

MILESTONES:

- Two journal papers on Phase (1) - August 1995.
- Ph.D. Thesis, journal paper on Phase (2) - August 1996.

DELIVERABLES:

(1) A library of experimentally verified connection truss models - a conceptual advance in that it provides designers with a detailed understanding of connection behavior and (2) a codifiable connection design methodology - the foundation for technological advances: new connection details suited for automation and earthquake resistance.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Progress reports are made twice per year to the PCI Committee on ATLSS and PRESSS. Technology transfer occurs through work on professional committees responsible for codes and design manuals: Dr. P. Mueller is a member of ACI/ASCE Committee 445, Shear and Torsion, PCI Connection Details Committee, and PCI Seismic Committee.

RESEARCH SUMMARY

TITLE: ATLSS Connections and Structural Systems (ADC-03)
TEAM LEADER: L.W. Lu (CE), B.V. Viscomi (CE)
TEAM MEMBERS: R. Fleischman (CE), K. Kanatharana (CE), M.R. Kaczinski (CE), N.D. Perreira (ME), E.J. Kaufmann (Mtl Sci), B.R. Somers (Mtl Sci), Effort Foundry

RESEARCH ISSUES ADDRESSED:

The objective of this project is to develop a family of connections with enhanced fabrication and erection characteristics. The goal is to provide structural systems in steel, concrete and composite construction that are efficient and economical while providing improvements in safety at the construction site and quality of the structure.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address key issues of connections, systems methodology for design and computer integration of design and construction. The project is fully coordinated with the activities of project ADC-09: ATLSS Integrated Building Systems, and the completed project IFC-02: Automated Construction Systems.

APPROACH; EXPERIMENTAL PLAN:

The present activities are focused on an innovative precast structural system for low- to mid-rise buildings in moderate earthquake zones. The ATLSS Precast Concrete System (APC) is composed of two framing systems. (1) an interior framing system and (2) a peripheral framing system. The interior framing system will resist gravity loading only and be of conventional design. The peripheral system, designed to resist lateral loading due to wind and earthquakes, utilizes two new connection schemes called the ATLSS beam-to-column (ABC) connection and the ATLSS beam-to-beam (ABB) connection.

RELATED WORK ELSEWHERE:

The research in developing connections with self-guiding erection characteristics is unique to the ATLSS center. A patent application has been filed for the ATLSS steel connection. There are research activities in the areas of automated building construction and related areas in Japan and in several European countries.

HOW ATLSS' WORK IS DIFFERENT:

The emphasis is on improving the constructability of structural systems through an integration of crane technologies and automated assembly/erection methodologies with structural connection design.

MILESTONES:

- Completing the planned tests of the Modified ATLSS Passage-Type (MAPT) connections.
- Completing the planned tests of the ATLSS Nodal Type (ANT) connections.
- Completing the development of design methodologies for MAPT system.
- Completing the development of design methodologies for ANT system.

DELIVERABLES:

A family of structural connectors with enhanced fabrication and erection characteristics for use in steel, concrete and composite structures. The impact of these connectors, together with the automated construction systems, will be to increase safety, productivity and quality of the construction process at the job site.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

- Steel Founders' Society of America has indicated strong interest in providing technical assistance in design of the castings for the connectors.
- Technology of ATLSS connections has been transferred to DuPont Engineering through field trails.
- Interests in the ATLSS connections and the automated construction system has been expressed by a number of U.S. and foreign firms. Numerous new inquiries have been received after articles on the connections appeared in several "trade" publications.

RESEARCH SUMMARY

TITLE: High-Performance Steels for Construction (ADC-06)
TEAM LEADER: R.D. Stout (Mtl Sci), J.H. Gross (Mtl Sci)
TEAM MEMBERS: R. Sause (CE), B.R. Somers (Mtl Sci), A.B. McGee (Mtl Sci), T.J. Todaro (Mtl Sci)

RESEARCH ISSUES ADDRESSED:

Fabricability and durability of structures; systems methodology for design. The advantages of high performance steels must include improved weldability at no increase in cost. Current 70 and 100 ksi yield-strength structural steels must be preheated at significant cost to avoid HAZ cracking.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The project addresses the strategic objective of improved performance of new and existing structures. Proof-of-principle and prototype testing is required to document the suitability of new high-performance steels for infrastructure applications. The suitability of the new steels in mechanical properties and weldability must first be demonstrated.

APPROACH; EXPERIMENTAL PLAN:

Previous experimental heats of 100-ksi and 70-ksi steels have exhibited encouraging combinations of strength, notch toughness, and weldability. Four additional heats will be designed to enable further efforts to extend the useful range of thickness, lower the yield-tensile ratio, and optimize the thermo-mechanical processing parameters such as rolling finishing temperature, reaustenitizing temperature, quenching rates, etc.

RELATED WORK ELSEWHERE:

The use of thermo-mechanical treatments to enhance the mechanical properties of high-strength steels has been investigated in Europe and Japan for several years. More recently the NAVSEA Title III program evaluated 70 to 100 ksi yield strength steels that were melted in the USA and thermo-mechanically processed in Japan. Mechanical property and weldability tests are underway. FHWA is sponsoring a study of TMCP (thermo-mechanical control process) steels for bridges in cooperation with AISI.

HOW ATLSS' WORK IS DIFFERENT:

The compositions selected for the ATLSS study have not been previously considered. In addition, CRAQ processing has not been previously evaluated. Results on earlier heats processed by the CRAQ practice were encouraging. Favorable results would be very important because American plate producers are not equipped for CRDQ but are for CRAQ.

MILESTONES:

The project began in April 1993 and will be completed in 1996. Interim milestones are scheduled for June 1995, December 1995, and July 1996.

DELIVERABLES:

- Papers covering the work through June 1994 are scheduled for presentation in October 1995.
- T.J. Todaro's M.S. thesis is scheduled for May 1995. A.B. McGee's M.S. thesis is scheduled for May 1996. Both theses will be prepared as papers for publication.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The U.S. Steel Technical Center melts the experimental steels, provides CRDQ processing, and USS and Lukens representatives cooperate with Lehigh University technically. The studies currently underway significantly influenced the proposed FHWA study and ATLSS has been asked to participate as a partner in the FHWA/AISI program. The planned papers will transfer the technical information to the public domain.

RESEARCH SUMMARY

TITLE: Integrated Building Systems Research And Demonstration Project (ADC-09)
TEAM LEADER: B.V. Viscomi (CE), L.W. Lu (CE)
TEAM MEMBERS: W. Lawrence (CE), K. Wyncott (CE), M.R. Kaczinski (CE), E.J. Kaufmann (Mtl Sci), V. Stellakis, J. Daniels, D. Hardwick (CE), undergraduates. Interstate Fabricators, Falcon Steel Co., DuPont

RESEARCH ISSUES ADDRESSED:

The objective of this project is to design, fabricate, erect and evaluate building *systems* with a focus on providing a computer-integrated systems approach to these activities. The long-term intent is to develop a family of structural systems in concrete, steel and composite construction, with enhanced fabrication and erection characteristics.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address the key issues of connections, automated construction tools and systems methodology for design. This research is inherently interdisciplinary, as interaction with industry, government and other ATLSS efforts is essential to the successful conclusion of the project.

APPROACH; EXPERIMENTAL PLAN:

The rationale for this project is three-fold. It will:

1. Contribute to the cluster objective of implementing the overall ATLSS integrated approach to design, fabrication, erection and monitoring of structural systems.
2. Provide a well-defined prototype structure for which the various automated construction (erection) concepts and systems can be tested before field implementation.
3. Provide a test structure for which new computer-controlled testing techniques can be developed and implemented. This will emphasize multi-directional loading as well as pseudodynamic testing.

RELATED WORK ELSEWHERE:

Related research in integrated building systems incorporating automated construction and self-guiding connections is unique to the ATLSS center in the United States. There is ongoing research in these areas in Japan and in several European countries.

HOW ATLSS' WORK IS DIFFERENT:

The emphasis is on improving the constructability of structural systems through an integration of crane technologies and automated assembly/erection methodologies with structural connection design.

MILESTONES:

- Development of phase III ATLSS connector suitable for larger structures including bridges.
- Erection/evaluation of overall semi-rigid frame and composite frame structural systems.
- Technology transfer and field implementation.

DELIVERABLES:

A family of structural systems in concrete, steel and composite construction with enhanced fabrication and erection characteristics to increase safety, productivity and quality of the construction process at the job site.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Two demonstration projects, two DuPont facilities, a cooperative research and development agreement (CRADA) has been reached with NIST. Cooperative efforts are also underway with Steel Founders' Society of America and Effort Foundry.

RESEARCH SUMMARY

TITLE: Development and Evaluation of New Floor Framing Systems for Gravity Loads (ADC-10)
TEAM LEADER: S. Pessiki (CE), R. Sause (CE), S. Slaughter (CE)
TEAM MEMBERS: R. Prior (CE), W. VanZyverden (CE)

RESEARCH ISSUES ADDRESSED:

The project has two objectives: (1) explore the development of new floor framing systems for gravity loads, focusing on precast concrete systems for office buildings; and (2) develop a methodology for the systematic comparison and evaluation of different floor framing systems.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

This project addresses the ATLSS strategic objective of Improved Performance of New and Existing Structures. Specifically, the floor systems developed in this project will result in more serviceable and efficient building structures.

APPROACH; EXPERIMENTAL PLAN:

The approach consists of four tasks. Task 1 assesses existing and emerging floor framing systems; and includes surveying existing and emerging systems, developing assessment criteria to evaluate these systems, and applying the assessment criteria to these systems. Task 2 develops new floor framing system concepts; and includes identifying problems and opportunities with existing systems, proposing new system concepts to address the problems and opportunities, and applying the assessment criteria developed in Task 1 to the proposed systems. Task 3 is a detailed design development of one or more of the concepts developed in Task 2. Task 4 is a detailed experimental, analytical, and economic evaluation of the systems that emerge from Task 3.

RELATED WORK ELSEWHERE:

Related work has been done at the Center for Infrastructure Research at the University of Nebraska. The work at Nebraska has been limited to the development of a precast floor framing system that minimizes the depth of the structural system. Other related research includes the NSF-funded PREcast Seismic Structural Systems (PRESSS) program, which emphasizes seismic performance.

HOW ATLSS' WORK IS DIFFERENT:

The ATLSS work takes a system view, identifying a full range of factors that influence the success of a particular floor system. Our work focuses on how the structural system may better accommodate the mechanical and other systems in a building while trying to optimize the floor system with respect to other criteria such as the overall floor-to-floor height.

MILESTONES:

The research has advanced to the point where detailed structural designs have been performed for a new system called the stub-girder system. Present work is directed towards experimental evaluation of this system. A report on the results of this experimental program will be completed by May 1996.

DELIVERABLES:

Deliverables include: (1) a survey and assessment of existing and emerging precast concrete framing systems for building structures; (2) an initial framework for the systematic assessment of precast floor framing systems; (3) proposed new precast concrete floor systems; and, (4) experimental evaluation of the stub girder system.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Extensive industry involvement has been a key feature of this project since its inception. In addition to project panel meetings, the progress of this project is reviewed and commented on each year on a regular basis by the PCI Committee on Research and Development, and by the PCI Committee on ATLSS/PRESSS. The status of the project was also discussed with several key industry professionals at the FIP Congress in Washington in May 1994. Publications include two journal papers, one conference paper, and 2 ATLSS reports.

RESEARCH SUMMARY

TITLE: Modular Design and Construction of Low and Mid-Rise Buildings (ADC-14)
TEAM LEADER: S. Slaughter (CE), R. Sause (CE)
TEAM MEMBERS: C. Farschman (CE), M. DeLaTorre (CE), R. Hendricks (DuPont Eng., CE)

RESEARCH ISSUES ADDRESSED:

The project will: (1) identify opportunities for non-traditional fabrication and erection (modular construction) methods in buildings; (2) develop procedures for selecting modular construction methods, and for designing modules and preassembled components; and (3) develop new structural concepts for modular construction.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The project addresses the ATLSS strategic objective of Improved Performance of New and Existing Structures. Successful development of new modular systems should result in structures with improved fabrication and erection efficiency and safety.

APPROACH; EXPERIMENTAL PLAN:

The research project involves the following tasks: (1) investigate current modular construction practices, issues, and opportunities through study of the public literature and discussions with selected industry representatives; (2) analyze opportunities in the current design-fabrication-erection practice for buildings and identify those for which modular construction offers the greatest potential benefits; (3) study application of current modular construction practices to the opportunities identified in (2); (4) develop procedures for selecting appropriate levels of prefabrication and preassembly, and for designing modules and preassembled components; and (5) develop new modular construction concepts (including the modular construction practices and the structural concepts that exploit modular construction) to address the opportunities identified in (2).

RELATED WORK ELSEWHERE:

Related research has been funded by the Construction Industry Institute (CII). This earlier work was directed at decision processes for selecting modular construction methods. No current work examines the metrics of modular construction methods or identifies opportunities for modular techniques.

HOW ATLSS' WORK IS DIFFERENT:

The ATLSS work involves the development of new structural concepts for modular construction, as well as the technology selection and design procedures required to utilize these concepts effectively. ATLSS is relying heavily on input from industry on the advantages and disadvantages of current modular construction methods, and on the future opportunities for these methods.

MILESTONES:

- ATLSS Report 94-11 on survey of current modular construction practices and the related issues and opportunities;
- Report on metrics of modular construction techniques for building frame structures by August 1995.
- Report on recommended procedures for selecting modular construction methods and designing of modules and preassembled components by May 1996.

DELIVERABLES:

The project will produce a survey of current modular construction practices and the related issues and opportunities; recommended procedures for selecting modular construction methods; recommended procedures for designing modules and preassembled components; and new modular concepts for building frame structures.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The project vision was developed in conjunction with an ATLSS industry partner, DuPont Engineering, which is an integral part of the project team. The project was presented to an industry panel which included several large design and construction companies, in May 1993. During 1993, individuals from 31 companies were interviewed as part of the survey of current modular construction practices. An industry advisory panel was convened consisting of representatives of engineering design firms, steel fabricators, erectors, labor organizations, and owners of constructed facilities.

RESEARCH SUMMARY

TITLE: Aluminum Latticed Spherical Domes (ADC-16)
TEAM LEADER: C.N. Kostem (CE)
TEAM MEMBERS: A. Maze (CE), J.E. Bower (CE)

RESEARCH ISSUES ADDRESSED:

The objectives were (a) to analytically determine buckling and snap-through behavior of single layer aluminum latticed spherical domes and (b) to determine the state of the practice for aluminum latticed domes from literature and industry interactions.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

By providing input to the behavior and instability limit state of large aluminum dome structures, this project addressed the strategic objective of improved performance of large structural systems.

APPROACH; EXPERIMENTAL PLAN:

Computer-based non-linear finite element analyses were conducted using ANSYS, and using prototype single layer dome designs and dimensions provided by the sponsor. Comparisons included the response of bare domes to domes covered by thin aluminum cladding, the effect of uniform snow load to a half-dome snow load, and the effect of perimeter edge condition. Snap-through buckling loads from the finite element analyses were correlated with existing simplified formulas for latticed shells that are based on continuum theory, and modified formulas better matching the finite element results were developed and recommended for a new state-of-practice.

RELATED WORK ELSEWHERE:

Limited recent studies have been conducted at some U.S. universities on similar structures, e.g., nonlinear analysis of Glulam Timber domes at WV Univ., and a nonlinear buckling analysis of an arena at Univ. of Wyoming. At the U.K. University of Surrey and at University of Tokyo, single and double layer latticed domes have been analyzed for specific domes being constructed. Temcor Corporation has reported buckling tests and analyses for the aluminum domes it engineers and supplies.

HOW ATLSS' WORK IS DIFFERENT:

Two major suppliers of the structures, Conservatek Industries and Temcor Corporation, were not using non-linear analyses to estimate snap-through, although Temcor was beginning to. Our work stressed non-linear analysis and is the first we know of where ANSYS was used for analyzing these structures.

MILESTONES:

- Initial non-linear computational results sent to Conservatek in 8/93
- Industry meetings with Conservatek and Temcor at ATLSS in 11/93
- Literature and state-of-practice review completed by 2/15/94.
- Final report draft sent to Conservatek in 4/94.
- Research was MS thesis for Mr. Maze in 5/94.
- Final ATLSS report, No. 94-07, issued June 1994.

DELIVERABLES:

Guidelines were recommended for using non-linear analyses for snap-through buckling prevention for single layer aluminum latticed spherical domes. Guidelines for choosing non-linear analyses vs. simplified continuum analyses were provided, and a new state-of-the-practice expression was developed.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

This project was partially funded by Conservatek Industries of Conroe, Texas. The original scope and the goals of the investigation were jointly developed by Conservatek engineers and the ATLSS researchers. TGB Partnership provided in-kind engineering consultation to us for Conservatek. Temcor Corp. discussed their work on this type of structure with us. Technical meetings at ATLSS were held with representatives of all these firms.

RESEARCH SUMMARY

TITLE: Behavior of Large-Scale Spirally Reinforced High Strength Concrete Columns (ADC-17)
TEAM LEADER: S. Pessiki (CE)
TEAM MEMBERS: A. Pieroni (CE)

RESEARCH ISSUES ADDRESSED:

The objective of this research is to explore the behavior of spirally-reinforced high strength concrete columns under the action of monotonically increasing axial load.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

By addressing the issue of spirally-confined high strength concrete columns this project will provide critically needed information to practicing engineers engaged in the design of structures, and help avoid possible future need for expensive retrofit of inadequate structures, as identified by improved performance of new and existing structures.

APPROACH; EXPERIMENTAL PLAN:

The research involves concentric axial load tests of spirally-reinforced concrete columns constructed with perimeter longitudinal reinforcement. Primary variables include concrete compressive strength, longitudinal reinforcement ratio, and spiral steel size/pitch. All columns are designed according to current ACI 318 Code requirements. Analysis of the experimental results includes a comparison with existing analytical models for behavior.

RELATED WORK ELSEWHERE:

Researchers at several other universities are also exploring the strength and ductility of a variety of reinforced concrete members made with high strength concrete, including columns, prestressed beams, and non-prestressed beams.

HOW ATLSS' WORK IS DIFFERENT:

Size effects may play an important role in the axial load behavior of spirally reinforced high strength concrete columns. The large-scale testing capabilities of the ATLSS laboratory allows essentially full-scale specimens to be tested, thereby removing much of the uncertainty that exists in previous results obtained with small-scale specimens.

MILESTONES:

The initial experimental program was completed in 1994. An ATLSS report that describes the results of the research will be completed in summer 1995.

DELIVERABLES:

Deliverables include an evaluation of the strength and ductility of large-scale spirally reinforced high strength concrete columns.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Aspects of this project were the results of discussions with Dr. Anthony Fiorato of the Portland Cement Association (PCA). Based on this interaction, a proposal was submitted by ATLSS to the PCA to perform large-scale tests of tied high strength concrete columns. PCA is funding this work, which is now in progress.

RESEARCH SUMMARY

TITLE: Inelastic Behavior of Members and Frames Fabricated from High Performance Steel (ADC-18)
TEAM LEADER: J. Ricles (CE), R. Sause (CE), T.K. Sooi (CE)
TEAM MEMBERS: P. Green (CE), E.J. Kaufmann (Mtl Sci)

RESEARCH ISSUES ADDRESSED:

Application of new, enhanced-performance materials to construction; new design concepts and structural forms to exploit the advantages of the new materials; development of design specifications to enable the new materials to be used safely and efficiently.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The project addresses ATLSS' strategic objective of Improved Performance of New and Existing Structures. Successful application of high performance steel (HPS) should result in more efficient, competitive structures with improved performance characteristics.

APPROACH; EXPERIMENTAL PLAN:

The research is divided into three tasks. Task 1 assesses the inelastic behavior of high performance (HPS) beams with standard shapes. Analytical research to model the inelastic flexural behavior of HPS members and frames is planned for Task 2. Finally, the inelastic behavior of multi-story structures fabricated using HPS and subjected to gravity and seismic load is investigated experimentally in Task 3.

RELATED WORK ELSEWHERE:

Similar work has been done in Japan for high strength steel produced in Japan. We are not aware of similar ongoing work in the U.S.

HOW ATLSS' WORK IS DIFFERENT:

The research project is focused on steel that is commercially produced in the U.S.

MILESTONES:

- Completion of Task 1 experimental work by summer 1995.
- Development of analytical models for high performance steel flexural members by fall 1995.
- Analytical study of inelastic behavior of frame structures in fall 1995.

DELIVERABLES:

Assessment of inelastic behavior of standard-shape high performance steel (HPS) members. Structural forms for HPS members with adequate inelastic behavior. Analytical model to simulate inelastic flexural behavior of HPS members. Assessment of inelastic behavior of HPS frame structures. Recommended design specifications.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The project has received interest from representatives of several steel producing companies. Material needed for the experimental work may be provided by Lukens Steel Co. The steel industry has a general interest in the application of high performance steel in construction. The design concepts, structural forms, and recommended design specifications developed by the project will directly address industry need sin this research area.

RESEARCH SUMMARY

TITLE: Innovative Bridge Designs Using Enhanced Performance Steels (ADC-E2)
TEAM LEADER: R. Sause (CE), J.W. Fisher (CE), J. Kulicki (Modjeski & Masters, CE)
TEAM MEMBERS: B.R. Somers (Mtl Sci), S. Slaughter (CE), Z. Li (CE), K. Homma (CE)

RESEARCH ISSUES ADDRESSED:

The project will: (1) determine the feasibility for using high-performance steel (HPS) in highway bridges, focusing initially on the potential for utilizing HPS in current bridge forms, and then focusing on new bridge forms which may make more effective use of HPS.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The project addresses the strategic objective of Improved Performance of New and Existing Structures. Successful application of high-performance steel should result in more efficient, competitive structures with improved performance characteristics.

APPROACH; EXPERIMENTAL PLAN:

The research project involves the following tasks: (1) review domestic and international bridge designs for the use of currently-available high-strength steel; (2) study the potential for high-performance steel (HPS) in current bridge designs by redesigning several recently-constructed bridges in HPS considering the limit states of strength, deflection, stability, and fatigue, and by assessing the potential advantages of HPS over currently-used steels; (3) develop innovative design concepts for highway bridges using HPS by conducting a workshop of invited bridge engineers and consultants to generate initial concepts, and by developing preliminary designs of the most promising concepts; and (4) develop recommendations for HPS research and potential changes to design codes to allow better utilization of HPS in highway bridges.

RELATED WORK ELSEWHERE:

Related research is being initiated in Japan and Germany. We are not aware of similar ongoing work in the U.S.

HOW ATLSS' WORK IS DIFFERENT:

The ATLSS work involves the development of new highway bridge concepts to exploit high-performance steel (HPS) in the U.S., considering current U.S. highway bridge design and construction technology and the potential to advance this technology.

MILESTONES:

- Workshop held in Arlington, VA in February 1994.
- Work completed on Task 1 and 2.
- Project Advisory Committee Meeting held in Mechanicsburg on February 24, 1995. Project behind schedule. Time extension has been granted.

DELIVERABLES:

State-of-the-practice report on the domestic and international use of high-strength steel in highway bridges; assessment of the potential for high-performance steel (HPS) in current bridge designs; innovative design concepts for using HPS in highway bridges; and recommendations for HPS research and potential changes to design codes to allow better utilization of HPS in highway bridges.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The project is a joint effort with Modjeski & Masters, Inc., a well-known bridge engineering firm and an ATLSS partner, and the University of Michigan. The tasks outlined above are being carried out in conjunction with Modjeski & Masters. The project is funded by the Federal Highway Administration. The project has received significant interest from the steel industry, and several meetings with steel industry representatives have been held to receive their input.

RESEARCH SUMMARY

TITLE: Axial Load Behavior of Tied High-Strength Concrete Columns (ADC-E4)
TEAM LEADER: S. Pessiki (CE)
TEAM MEMBERS: W. Lin (CE), A. Pieroni (CE)

RESEARCH ISSUES ADDRESSED:

The objective of the research is to evaluate the axial load capacity of high-strength concrete columns with rectangular ties. Emphasis is placed on determining whether current minimum tie requirements are applicable to high-strength columns. Behavior parameters of interest include axial strength, axial deformation capacity, and failure mode.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

High-strength concrete is a relatively new material being used with existing design approaches that were originally developed for lower strength, generally more ductile concrete. This research will provide critically needed information to practicing engineers designing reinforced concrete structures that use high-strength concrete compression members.

APPROACH; EXPERIMENTAL PLAN:

A total of nine large-scale (16 in. square cross-section) columns are included in the test program. Variables include concrete compressive strength and tie spacing. The nine specimens in the program comprise of a 3x3 test matrix in concrete strength (5-6, 10, and 14-16 ksi) and transverse reinforcement spacing (4, 8, and 16 in. on centers). In addition to the experimental work, existing analytical models are used to predict the axial load-deformation behavior of the columns. These predictions will be compared with the experimental results.

RELATED WORK ELSEWHERE:

Researchers at several other universities are also exploring the behavior of reinforced concrete members made with high-strength concrete, including columns, prestessed beams, and non-prestressed beams.

HOW ATLSS' WORK IS DIFFERENT:

Size effects may play an important role in the axial load behavior of tied high-strength concrete columns. The large-scale testing capabilities of the ATLSS laboratory are used to test essentially full-scale specimens. This removes much of the uncertainty associated with small-scale experiments.

MILESTONES:

- Testing of the first two series of columns will begin in May 1995.
- The test date for the third series of columns will be determined by the actual pour date. It is anticipated that these columns will be tested at an age of about 56 days..
- A project report will be submitted in August 1995. This will include the results and evaluation of all tests performed to that date.

DELIVERABLES:

Deliverables include an evaluation of the strength and ductility of large-scale tied high-strength concrete columns, and an evaluation of the suitability of existing design methods for such members.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

This research is sponsored by the Portland Cement Association (PCA), and the test program was developed jointly with researchers at the PCA. The project was motivated by previous work performed as part of project ADC-17.

RESEARCH SUMMARY

TITLE: Behavior of Williamsburg Bridge Orthotropic Deck (ADC-E5)
TEAM LEADER: M.R. Kaczinski (CE)
TEAM MEMBERS: J.W. Fisher (CE), F.E. Stokes (ME), P. Lugger (CE)

RESEARCH ISSUES ADDRESSED: In the rehabilitation of the significantly deteriorated Williamsburg Bridge, officials made a major decision by selecting a closed-rib orthotropic deck to replace a deteriorated grillage deck on vehicular lanes cantilevered from the main bridge structure. Major design, analysis, & fabrication issues are being studied in a first-of-a-kind full-scale test.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:
Two major thrust areas of ATLSS are renewal engineering and innovative structural systems for civil infrastructure systems. This study addresses all these areas.

APPROACH; EXPERIMENTAL PLAN:
A full-scale 60-foot-long by 20-foot-wide prototype segment of the bridge structure with the orthotropic-deck system was commercially fabricated and erected in the ATLSS Laboratory. Cantilevered from the Laboratory's reaction wall, just as the actual deck structure is to be cantilevered from the main bridge, the prototype was initially tested with static loading to obtain its baseline behavior under vehicular dead weight. Later, fatigue testing was begun, simulating the continual passage of two HS 20-44 trucks traveling side-by-side in the same direction. After two million cycles and the deck's fatigue resistance was verified, some final design decisions were made, and the testing is currently continuing to ten million cycles. Throughout all tests, a significant amount of instrumentation is being used. If additional funding is obtained, the ultimate fatigue resistance of the prototype at a greater stress range may be conducted after the fatigue tests.

RELATED WORK ELSEWHERE:
Finite element analyses of the bridge-deck system are being conducted by Steinman Engineers, and their analysis results are being correlated with test measurements.

HOW ATLSS' WORK IS DIFFERENT:
No previous full-scale orthotropic bridge-deck systems have been tested. Further, no cantilevered systems have been tested and no fatigue tests simulating side-by-side truck passage have been conducted.

MILESTONES:
Installation of the prototype bridge in the ATLSS Laboratory was completed in December 1994. Baseline static testing was completed in February 1995. Two-million cycles of fatigue testing were attained in April 1995. Ten-million cycles of fatigue testing are expected to be attained by December 1995.

DELIVERABLES:
- Fatigue resistance data on diaphragm connection details for closed-rib orthotropic decks.
- Methods to repair or retrofit these details when fatigue cracks initiate.
- Local values of stress that can be used to verify the accuracy of finite element analyses.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:
This study is sponsored by the New York City DOT, New York State DOT, and FHWA. Steinman Engineers are the design engineers for the bridge. All the sponsors and Steinman engineers meet at ATLSS at least monthly to review progress and plan continuing actions.

RESEARCH SUMMARY

TITLE: Design Rules for Double-Hull Ship Attachment Systems (ADC-E6)
TEAM LEADER: R.J. Dexter (Appl Mech), R. Roberts (ME)
TEAM MEMBERS: J. Hopkinson (Nav Arch), J.W. Fisher (CE)

RESEARCH ISSUES ADDRESSED:

Foundations are structures used to mount piping and equipment on ship hulls. Traditional designs are overconservative and expensive to fabricate. The ATLSS project verified that AISC fatigue and web crippling criteria can be used to design cost-effective lightweight foundations for double-hull ships.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

This project addresses the ATLSS "strategic objectives" of: 1) Improved Performance of New and Existing Structures, and; 2) Improved Maintainability and Repairability. The following ATLSS "key issues" were also addressed: 1) Knowledge Base on Large-Scale and/or Complete Structural Systems, and; 2) Connections and Structural Systems.

APPROACH; EXPERIMENTAL PLAN:

A family of standard designs such as frames or trusses fabricated from angle sections were developed. The capacity of the cellular double-hull structure to support concentrated loads normal to the hull (e.g. from foundations or from docking) was determined through full-scale web-crippling tests and finite-element analyses (FEA). The lowest-cost attachment detail was evaluated, i.e. the angles are fillet welded directly to the inner hull (without pads or backup structure) with a generous tolerance for eccentricity between the internal girder and the angle leg. Full-scale fatigue tests were conducted to verify the fatigue performance of these eccentric attachments. In addition, four different pipe hanger designs have been evaluated in full-scale fatigue tests. A design procedure was proposed which balances the level of effort and refinement of the FEA with a realistic required accuracy.

RELATED WORK ELSEWHERE:

Since the early 1970's, there have been several studies with the aim of reducing the time, labor, and materials for manufacture and installation of foundations as well as the installation of equipment and systems. This research led to the development of a family of standard foundation designs for equipment and machinery up to 700 kg mounted on simple lightweight frames or trusses consisting primarily of angle shapes.

HOW ATLSS' WORK IS DIFFERENT:

The lightweight foundations in previous studies were designed for mounting to a conventional hull. The ATLSS project adapted these foundation designs for the advanced double hull design. The ATLSS project was also the first to conduct experiments on the structural behavior of these foundation designs.

MILESTONES:

Initial project work began in August 1992 and was completed in September 1993. This experience lead to a subsequent project sponsored by Ingalls Shipbuilding to study pipe hangers. This project ends in June 1995.

DELIVERABLES:

The final report on the initial study provided a design procedure, guidance on finite-element analysis, as well as documentation of the experiments and analyses. The report on the second study is due in June 1995.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The first project was sponsored by the U.S. Navy. VIBTECH, Inc., a Naval Architecture firm, provided expertise on the design of the details as well as parametric finite-element analyses. Some of the specimens were fabricated by Ingalls Shipbuilding. It was estimated that about $11 million per ship could be saved using these standard foundation designs. Two papers have been accepted for publication from this project. The follow-on project is sponsored by Ingalls Shipbuilding.

RESEARCH SUMMARY

TITLE: Strength and Ductility of Concrete Columns Reinforced by Fiber Composite Tubes (IFC-E2)
TEAM LEADER: L.W. Lu (CE)
TEAM MEMBERS: K. Kanatharana (CE)

RESEARCH ISSUES ADDRESSED:

Provide a background toward the understanding of the behavior of fiber-composite (FC) reinforced concrete columns.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

Developing the knowledge base for applications of FC tubes with structural concrete is part of the strategy for developing innovative structural systems.

APPROACH; EXPERIMENTAL PLAN:

Behavior and failure modes of FC reinforced concrete columns were experimentally studied under uniaxial compressive loading using two types of FC tubes and three column configurations. Based on the findings, a theoretical tool for predicting the column behavior and the potential strength and ductility increase of both fiber-composite and concrete materials was developed.

RELATED WORK ELSEWHERE:

M.N. Fardis and H. Khalili studied behavior of concrete columns wrapped with FC fibers, whereas C.E. Kurt investigated behavior of concrete-filled plastic pipe columns.

HOW ATLSS' WORK IS DIFFERENT:

This study was geared toward the use of FC tubes in new concrete construction, whereas Fardis and Khalili's study was more suitable for repair and retrofit of existing structures. In addition, the FC tubes had superior strength and ductility when compared to the plastic pipe used in Kurt's study.

MILESTONES:

- Research program completed.
- An M.S. thesis and an ATLSS report (No. 94-14) based on the research program were issued.

DELIVERABLES:

- Load capacities of FC reinforced concrete columns under uniaxial compressive loading.
- Background toward understanding of behavior of FC reinforced concrete columns.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Smith Fiberglass Products, Inc. and Morrison Molded Fiber Glass, Co. donated the FC materials used in the research program.

RESEARCH SUMMARY

TITLE: Optimized Weld Metal Properties For Ship Structures (IFC-E7)
TEAM LEADER: R.J. Dexter (Appl Mech)
TEAM MEMBERS: E.J. Kaufmann, (Mtl Sci), A. W. Pense (Mtl Sci), M. Ferrell (CE)

RESEARCH ISSUES ADDRESSED:

High strength steel with high toughness has been developed, but high strength weld metal with sufficient toughness has not. This project investigates the performance of high-strength steel joints with lower strength welds (i.e. undermatched), which have traditionally not been allowed.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

This project will facilitate more efficient and competitive shipbuilding. The strategic objectives of improved Maintainability and Repairability and Improved Performance as well as the key issue of connection are addressed.

APPROACH; EXPERIMENTAL PLAN:

Several critical high-strength steel joints are identified and the economic benefits of undermatching these joints are estimated. These economic benefits accrue from the reduced likelihood of hydrogen cracking and the associated reduction of preheat, inspection, and paperwork requirements, as well as increased deposition rates. Full-scale joints will be tested to failure, measuring the plastic strain in the weld and the baseplate. These tests were simulated using elastoplastic finite-element analysis to verify the reliability of such analysis. Similar analyses were used to study a variety of additional joints. The strength and ductility of these joints will be compared to similar joints with high-strength weld metal.

RELATED WORK ELSEWHERE:

Previous work has been accomplished at Southwest Research Institute. This verified adequate ductility and an economic benefit for undermatched pipeline girth welds.

HOW ATLSS' WORK IS DIFFERENT:

This is the first large-scale experimental program aimed at undermatched high-strength steel joints in surface ships.

MILESTONES:

- September, 1993 - Testing completed
- June, 1994 - Analysis completed
- October, 1994 - Selection of optimum joints
- October, 1994 - Completed guidelines
- October, 1994 - Project extended to perform additional tests
- June, 1995 - Final Report

DELIVERABLES:

1) Guidelines for application of undermatched welds in ship structure.
2) Software for estimating the performance of undermatched weld joints.
3) Preliminary work to begin the certification process to allow undermatched welds.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Bath Iron Works, a major U.S. shipyard, will participate by selecting joints, calculating economic benefits, and fabricating specimens. The work is performed for the Interagency Ship Structure Committee. Technology Transfer will include the deliverables noted above.

RESEARCH SUMMARY

TITLE: Performance of Advanced Weld Processes for Double-Hull Ship Construction (IFC-E10)
TEAM LEADER: E.J. Kaufmann (Mtl Sci)
TEAM MEMBERS: L.W. Lu (CE), P. Xu (Mtl Sci)

RESEARCH ISSUES ADDRESSED:

The objective of the research is to 1) demonstrate the feasibility of producing weldments and 2) evaluate the fatigue and fracture resistance of various weld process/joint configurations under consideration for construction of Advanced Double-Hull (ADH) ships for both naval and commercial applications.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project are consistent with the durability/longevity of infrastructure issues addressed in the ATLSS strategic plan.

APPROACH; EXPERIMENTAL PLAN:

Forty-five full-size weldment test specimens will be fabricated using five candidate weld process/joint configurations under consideration for fabrication of double hull cellular structure. Weld joints to be studied include longitudinal one-sided weld joints produced with high energy beam weld processes (non-vacuum electron beam and CO_2 laser beam) in a blind tee configuration, and one-sided beveled three plate tee electroslag joints fabricated with buried arc-GTAW, PAWS, and ESW process. Large scale fatigue tests will be conducted to evaluate the fatigue resistance of the five different weld joints. Static strength and fracture toughness tests will also be performed on several of the weld joint types.

RELATED WORK ELSEWHERE:

Research is part of the Navy's ADH Technology Program conducted by CD-NSWC. It enlarges upon similar research performed with Marinex International utilizing the electrogas weld (EGW) process.

HOW ATLSS' WORK IS DIFFERENT:

By utilizing full-scale test specimens, the fatigue test data obtained more accurately reflects the residual stress and weld discontinuity distributions existing in welded structures.

MILESTONES:

- Complete large-scale fatigue tests of 45 beam specimens.
- Perform post-test characterization of fractures and analysis of test data.
- Perform static strength and fracture toughness tests of weld joints.
- Prepare final report.

DELIVERABLES:

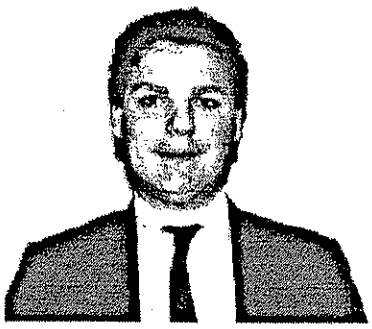
1) Large-scale fatigue and fracture toughness test data for the five candidate weld process/joint configurations.
2) Design guidance for using these weld joints in double-hull ships.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The research program is under the technical direction of Carderock Division - Naval Surface Warfare Center and is funded by the U.S. Navy through the Navy Joining Center and includes both industrial and academic participants including: Ingalls Shipbuilding, PTR-Precision Technologies Inc., Babcock and Wilcox, Oregon Graduate Institute, and Penn State Applied Research Lab. Project results will be useful to manufacturers of welding equipment and end users, particularly shipbuilders and fabricators, of other large welded structures.

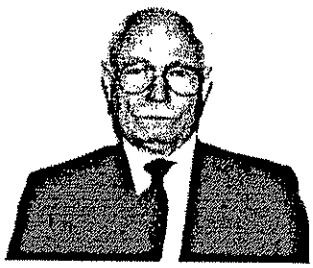
RENEWAL ENGINEERING

Thrust Leader



Prof. James Ricles
(CE)
(IMP-16, IMP-E8, IMP-E10)

Prof. Kazuhiko Kasai
(CE)
(ADC-15, IMP-E9)



Prof. Alex Ostapenko
(CE)
(IMP-E2, IMP-E10)

Prof. Stephen Pessiki
(CE)
(IMP-E10)

RESEARCH SUMMARY

TITLE: Performance and Rehabilitation of Multistory Steel Frames for Seismic/Wind Loads (ADC-15)
TEAM LEADER: K. Kasai (CE)
TEAM MEMBERS: C. Higgins (CE), Y. Fu (CE), X. Han (CE), A. Watanabe (CE), W. Eng (CE)

RESEARCH ISSUES ADDRESSED:

Key unresolved frame-dependent design issues for the common structural frames and for newer structurally attractive structural frames.

Testing with realistically simulated lateral and vertical loads of large magnitude to clarify the ultimate strength of full-scale structures.

Frame behavior with VE-damping.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

To provide realistic test and analysis data for conventional or new innovative frames whose design methods have been seriously incomplete due to lack of such data.

To create a "test bed" consisting of loading and support systems that will be re-used to test economically a variety of full-scale frames.

APPROACH; EXPERIMENTAL PLAN:

A series of multi-story frames having either innovative or conventional framing systems have been designed for full-size tests, where the frames represent the 3-story bottom portions of 10-story frames. The frames have steel beams and columns, and will be tested with at least six different framing schemes: (1) viscoelastically damped frame (VE-frame), (2) moment resisting frame with PR-connections (PR-MRF), (3) eccentrically braced frame with PR-connection, (4) moment resisting frame with ATLSS connections (ATLSS-MRF), (5) unbonded brace frame, and (6) other frames.

The gravity loads as well as lateral loads accumulated from top to the 3rd level of the multistory building are to be applied through several large capacity jacks. The P-Δ effects are to be simulated through an additional jack that assures the direction of the simulated gravity load. In some tests, the loads will be applied on a real-time basis when included members are strain rate sensitive.

RELATED WORK ELSEWHERE:

Studies on VE-frame have been conducted at SUNY Buffalo, U.C. Berkeley, and National Taiwan Univ. Studies on PR-MRF have been conducted at Purdue Univ., U.C. Berkeley, and Univ. of Minnesota. Studies on an unbonded steel brace frame have been carried out in Japan.

HOW ATLSS' WORK IS DIFFERENT:

The project addresses full-scale frame tests in contrast to the small-scale tests conducted elsewhere. The tests also employ lateral and vertical loads of extremely large magnitude. No full-size tests of this kind have been conducted for similar frames using extreme load conditions The PR-EBF as well as ATLSS-MRF are unique systems that have not been tested to date. The project also emphasizes accurate analytical response predictions considering cyclic loads.

MILESTONES:

A full-size VE-frame test is scheduled in Q3 1995; PR-MRF tests employing a variety of PR-connections are scheduled for Q4 1995, and a PR-EBF test scheduled in Q2 1996. Other frames are planned for 1996 depending on the availability of funding. Some tests for the critical frame components will also be performed in parallel with the frame tests.

DELIVERABLES:

Design guides for the various frames tested should result, and will be published along with the test data and findings.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Support for the project has been provided by 3M Company, Nippon Steel, Bethlehem Steel, Lukens Steel, and AISC. The 3M Company has also provided the VE-material, analysis, and results as well as advice regarding monitoring techniques for VE-damper response. The test and analysis will be publicized by both 3M and Nippon Steel. The project also has led to the establishment of a technical agreement between 3M and Nippon Steel.

RESEARCH SUMMARY

TITLE: Residual Strength Assessment and Repair of Corroded Offshore Tubular Bracing (IMP-16)
TEAM LEADER: J.M. Ricles (CE)
TEAM MEMBERS: M.F. Hebor (CE), P.C. Schonwetter (CE)

RESEARCH ISSUES ADDRESSED:

The research study had the objective of investigating the residual strength and repair of offshore platform bracing members which have corrosion damage.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The objective of the study fit the ERC's strategic objective in the area of improved performance of new structures and existing structures as well as improved maintainability and repairability of structural systems by addressing the key issue of durability and longevity of infrastructure.

APPROACH; EXPERIMENTAL PLAN:

The study involved experimental testing of large scale damaged specimens which have been damaged and repaired. The corrosion damage was inflicted by controlled grinding in order to study the dimensional parameters and their influence on residual strength and repair. The diameter-to-thickness (D/t) ratio was also considered as a sensitive parameter. Repair was performed using external sleeves and epoxy based grout. The assessment of residual strength of non-repaired members and the capacity of repaired members was accomplished by comparing the results from a series of tests on non-repaired specimens with results from a series of repaired specimens. The experimental study was complemented by an extensive analytical study involving nonlinear finite element analysis, as well as local buckling equation formulation and evaluation. The results include the strengths of non-repaired and repaired members, normalized with respect to their undamaged strength.

RELATED WORK ELSEWHERE:

Research related to corrosion of offshore tubulars is being conducted at Lehigh University under a separate joint industry project.

HOW ATLSS' WORK IS DIFFERENT:

The study involved parameterization of patch corrosion, epoxy based sleeve repair, and nonlinear finite element analysis.

MILESTONES:

- The experimental testing was completed in June, 1994.
- Nonlinear finite element analysis parametric studies are being completed.

DELIVERABLES:

A final report with design recommendations for repair of corroded tubular bracing, and recommendations of residual strength based on corrosion parameters.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

This study was spurred by interaction with several oil companies. The oil companies expressed the industry's need for this type of study. Interaction with the oil companies continued to keep the study useful for industry.

RESEARCH SUMMARY

TITLE: Residual Strength of Damaged and Deteriorated Offshore Structures (IMP-E2)
TEAM LEADER: A. Ostapenko (CE)
TEAM MEMBERS: A. Chowdhury (CE), M. Hebor (CE), R.W. Kowalik (Mtl Sci), J. Padula (CE), B.A. Wood (CE), J. Wood (Mtl Sci)

RESEARCH ISSUES ADDRESSED:

Experimental and analytical investigation of the ultimate capacity and post-ultimate residual strength of axially loaded tubular members damaged by dents, out-of-straightness, or overall and/or patch deterioration (corrosion). The tests on large-scale specimens were also utilized to study acoustic emission as a means of detecting damage.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The study fits ATLSS' strategic objectives for improved performance of new and existing structures as well as improved maintainability and repairability of structural systems by addressing the key issues of durability, longevity and improvement of infrastructure.

APPROACH; EXPERIMENTAL PLAN:

Tests were conducted on large-scale specimens salvaged from decommissioned oil production platforms or fabricated by following the industry standard procedure of cold-bending and welding. Two tests on small-scale specimens served to establish correlation with the many small-scale tests conducted elsewhere. The experimental results were used as a basis for an analytical study using geometrically and materially nonlinear FE analysis and several other methods. The "piggy-back" study of acoustic emission response during the large-scale tests enhanced the interdisciplinary scope of the project.

RELATED WORK ELSEWHERE:

Related experimental research on small-scale columns damaged by dents and/or out-of-straightness has been conducted in Norway and U.K. Some computational methods have been developed to correlate with these test results, empirically or analytically.

HOW ATLSS' WORK IS DIFFERENT:

The study involved testing full-scale (up to D=24.5" and L=36') damaged offshore tubular members, salvaged from decommissioned platforms or specially fabricated to simulate practical production methods (as opposed to the small-scale manufactured specimens tested elsewhere). Tested were also field-corroded specimens. Analysis of test specimens was made by using all available methods, including FEM & a new method developed concurrently with this project. Acoustic emission study was the first conducted on the types of members and loading tested.

MILESTONES:

Project Meetings with the sponsors were held at ATLSS or in Houston (at OTC) on the following dates: 5/9/90, 5/6/91, 5/31/91, and 6/24-25/92. The Final Project Report was issued in two volumes: ATLSS Report 93-03 (structural tests and analysis) and ATLSS Report 93-04 (acoustic emission study).

DELIVERABLES:

The principal deliverables were the final project reports for the two research areas. In addition, an M.S. (K.M. Donovan) and a Ph.D. (W.B. Kim) thesis on topics related to the project area were distributed to the sponsors.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The project was funded externally by five oil companies Chevron, Exxon, Mobil, Shell and Texaco), Steel Industry (AISI), the U.S. Department of the Interior (Minerals Management Service), and the Department of Energy of the United Kingdom (MaTSU), and the research served the needs of these sponsors. The salvaged specimens were provided by one of the oil companies.

RESEARCH SUMMARY

TITLE: Residual Strength and Grout Repair of Damaged Tubular Members (IMP-E8)
TEAM LEADER: J.M. Ricles (CE)
TEAM MEMBERS: T.K. Sooi (CE), W. Bruin (CE)

RESEARCH ISSUES ADDRESSED:

The research study has the objective of investigating the residual strength and repair of offshore platform bracing members which have dent damage.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The objective of the study fits the ERC's strategic objective in the area of Improved Performance of New Structures and Existing Structures as well as Improved Maintainability and Repairability of Structural Systems by addressing the key issue of Durability and Longevity of Infrastructure.

APPROACH; EXPERIMENTAL PLAN:

The study involves experimental testing of large scale damaged specimens which have been repaired. The dent damaged is inflicted under controlled conditions in order to study the parameter of dent depth on residual strength and repair. Another parameter being considered is the diameter-to-thickness (D/t) ratio. Repair is performed using complete interior grouting. In addition, other repair options are being assessed which includes grouted clamps. The assessment of residual strength of nonrepaired members and the capacity of repaired members is accomplished by comparing the results from a series of tests on nonrepaired dented specimens with repaired dented specimens. The experimental study is being complemented by an extensive analytical study involving nonlinear finite element analysis, as well as beam column and local buckling equation formulation and evaluation. The results of the data are to be organized where strengths of nonrepaired and repaired members are presented, and normalized with respect to their undamaged strength.

RELATED WORK ELSEWHERE:

Related research is being conducted at Texas A&M University, Lehigh University under a separate joint industry project, and in Europe (England and Norway).

HOW ATLSS' WORK IS DIFFERENT:

The study being conducted involves large scale testing, grout repair, in addition to nonlinear finite element analysis.

MILESTONES:

The second phase of the multiphase project began in June 1992 and will be completed in May 1995.

DELIVERABLES:

The study will result in a data base for the residual strength of dented tubular bracing. In addition, design recommendations for repair of dented tubular bracing will be formulated and included in a final report. This final report is to be delivered in May 1995.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Several oil companies have been involved with the project from its inception. These include: Unocal, Chevron, and Exxon. The principal investigator has attended meetings in the offices of these companies to discuss the research. Furthermore, visits were made to platforms Irine and Eva in California, both owned and operated by Unocal, to inspect damaged members and grout repair procedures. Transfer of the project's results is being done through the final report in addition to the presentation and publication of numerous papers.

RESEARCH SUMMARY

TITLE: Rehabilitation of Steel Bridges Through the Application of Advanced Composite Material (Joint Effort with Composite Material Center, Univ. of Delaware) (IMP-E9)
TEAM LEADER: D. Mertz (CE) Delaware; K. Kasai (CE)
TEAM MEMBERS: I. Hodgson (CE); V. Karbhari (CE) Delaware

RESEARCH ISSUES ADDRESSED:

The objective is to determine the feasibility of rehabilitating and strengthening existing corroded steel bridges through bonding of advanced composite materials to the steel. The project is an example application of the composite material technologies from other industries to civil engineering infrastructure.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The project is considered to be the renewal engineering research as well as innovative materials and structure research. It will be also extended to consider fatigue resistance of the retrofitted members, and will be related to life cycle engineering.

APPROACH; EXPERIMENTAL PLAN:

Experiments of the full-scale corroded steel beams with or without the composite material will be conducted. The specimens are wide flange steel beams size of W18. Two types of specimens are considered: One having long span thereby failing in flexure, and another having short span failing in shear.

The Lehigh experiment is an extension of small-scale test being conducted at Delaware. The elastic stiffness, yield and ultimate strengths, and ductility of the corroded members as well as retrofitted members will be observed. The results will be correlated with the analytical results based on detailed finite element modeling.

RELATED WORK ELSEWHERE:

Lehigh University and University of Delaware are the only institutions investigating efficiencies of the bonded composite material for a retrofit of corroded steel members.

HOW ATLSS' WORK IS DIFFERENT:

The project is based on a unique idea of fusion bonding between corroded steel and composite material. The work involves the development of the advanced composite materials as well as bonding technology.

MILESTONES:

Tests of full-size corroded steel beam with or without the composite material will be conducted in summer of 1995. In the following year, fatigue resistance will be monitored. Analytical simulation will be made by fall 1995 by considering the steel thickness reduced due to oxygenation. The effect on bond strength between the surfaces of steel and composite will be modeled based on Delaware's detailed study being carried.

DELIVERABLES:

The results and findings of the frame tests re to be published in the reports as well as journal and conference papers. Some of the publications should provide application guide for the technology.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

It is planned to develop an interaction with industries when a basic data is obtained.

RESEARCH SUMMARY

TITLE: Residual Strength and Repair of Damaged and Deteriorated (Corroded) Offshore Structures (IMP-E10)

TEAM LEADER: A. Ostapenko (CE), S.P. Pessiki (CE), J.M. Ricles (CE)
TEAM MEMBERS: T.W. Berger (CE), W.M. Bruin (CE), S.L. Chambers (CE), M.F. Hebor (CE), T-K Sooi

RESEARCH ISSUES ADDRESSED:

Three areas are addressed: (1) effect of corrosion damage on strength of tubular members, (2) non-destructive assessment of corrosion damage in the field, and (3) repair of dented members by grouting.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The study fits ATLSS' strategic objectives for improved Performance of New and Existing Structures as well as improved maintainability and repairability of structural systems by addressing the key issues of durability, longevity and improvement of infrastructure.

APPROACH; EXPERIMENTAL PLAN:

Area 1 - Corrosion Damage - Effect on Strength: Tests on salvaged tubular members with pronounced patch corrosion simulated by grinding. Results of FE and simplified analysis are used to develop an "engineering" method for evaluating residual strength. Area 2 - Corrosion Damage - Assessment in the Field: Survey of existing/emerging non-destructive techniques of field inspection of members in offshore structures for corrosion damage. Evaluation of the most appropriate of them for practical application. Area 3 -Repair of Dented Tubular Columns: Tests on heavily dented tubular columns unrepaired and repaired by internal grouting. Analysis by various methods, including FEM, will lead to recommendations for practical methods for evaluating the strength of repaired members.

RELATED WORK ELSEWHERE:

Related research on salvaged corroded members was conducted in an already completed ATLSS project (IMP-E2). Work on members with simulated patch corrosion is also conducted in another ATLSS project (IMP-E8).

A limited study on field assessment methods was recently carried out in the U.K. Related research on grout-repair of dented tubes has been conducted in Australia, U.K., at Texas A&M University, and in a concurrent ATLSS project (IMP-16).

HOW ATLSS' WORK IS DIFFERENT:

This ATLSS project covers new or broader ranges of corrosion and dent damage than research elsewhere. Corrosion assessment in the field is a very urgent area of investigation not systematically addressed by others.

MILESTONES:

A project meeting with the sponsors was held at ATLSS in August 1994 to present and discuss the work completed by then and planned for continuation. Work has been progressing essentially in accordance with the proposal, decisions were made on some modifications for future emphasis. Most of the experimental work has been completed. Main thrust is on the evaluation, analyses and recommendations.

DELIVERABLES:

The principal deliverables will be the final project reports for the respective research areas. Also, intermittent consultations with the sponsors and the presentations at the project meetings are additional forms of deliverables. It is expected that the research results will be published after the expiration of the one-year confidentiality period.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

the project is funded externally by three oil companies (Exxon, Mobil and Shell) and the U.S. Dept. of the Interior (Minerals Management Service) and thus directly responds to the needs of the oil industry. The analytical and design tools developed in the project are formulated for practical application.

CONDITION ASSESSMENT & LIFE PREDICTION

Thrust Leader

Dr. Robert Dexter
(Appl. Mech.)
(ADC-13, ADC-E1, ADC-E3, IFC-E8)

Prof. Haluk Atkan
(CE-Wayne State)
(EXP-03)

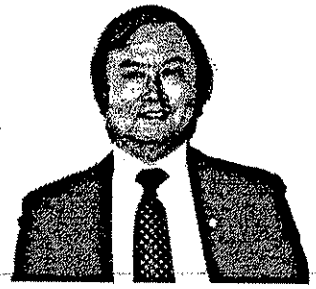
Prof. John Fisher
(CE)
(IMP-E1, IMP-E6)

Dr. Richard Granata
(Chem.)
(ADC-13, IMP-12, IMP-15, IMP-E3)

Mr. Mark Kaczinski
(CE)
(ADC-E1, ADC-E3)

Prof. Weiping Li
(EE)
(IMP-09)

Prof. Le-Wu Lu
(CE)
(EXP-03)



Prof. Ben Yen
(CE)
(IMP-E1, IMP-E6)

RESEARCH SUMMARY

TITLE: California State Univ. - Northridge: Outreach Undergraduate Research: Corrosion Fatigue of Structural Steels and Strength of Concrete Composite Structures (ADC-13)

TEAM LEADER: R.D. Granata (Chem), R.J. Dexter (Appl Mech), R. DiJulio (Eng.)
TEAM MEMBERS: L.W. Lu (CE); CSUN: Faculty: B. Bavarian, J. Shively: Students: A. Magee, T. Miller, C. Rodriguez, A. Salcedo, R. Palacios

RESEARCH ISSUES ADDRESSED:

- Engaging underrepresented undergraduate students in research supporting the research goals of ATLSS.
- Complementing ATLSS research on fatigue of structural steel and on the use of fiber-reinforced polymers to strengthen concrete.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

- This project addresses our strategic educational objective to have undergraduate and underrepresented students participate fully in the ATLSS program.
- The project also addresses the strategic research objectives of improved performance and improved maintainability of new and existing structures.

APPROACH; EXPERIMENTAL PLAN:

Planned work through June 1996 includes continuation of the corrosion fatigue tests on HAZ and weldment of HSLA 80 steel, and application of cathodic protection to improve performance of this steel in seawater.

The second project tested composite-reinforced concrete cylinders under compressive loads in order to determine if wrapping with E-fiberglass reinforced composites could enhance the strength and ductility of concrete. The influence of wrap thickness and cylinder size with parameters such as concrete strength, number of layers of fiberglass, and aging time were studied. Planned work through June 1996 includes investigation of alternative fibers (Kevlar 29, S-fiberglass) and resins, and environmental effects. A finite element computer model for predicting the stresses and elastic deformations of wrapped and unwrapped concrete cylinders will be developed.

RELATED WORK ELSEWHERE:

- ATLSS has done previous research on FRP-wrapped concrete cylinders. CSUN also has other composites research underway with NASA funding. Caltrans has begun to use FRP-wrapped concrete.
- Very limited seawater corrosion fatigue data exists for structural steel, and none for HSLA 80 steel.

HOW ATLSS' WORK IS DIFFERENT:

- Research into seawater corrosion of HSLA steel has not been previously conducted.
- The research with FRP wrapped concrete cylinders will extend the available database.

MILESTONES:

- CSUN students will work at Lehigh during the summers of 1995 and 1996.
- Progress report will be ready by June 1996.

DELIVERABLES:

- A compilation of seawater fatigue data usable by shipbuilders, designers, and the U.S. Navy.
- New data useful to structural engineers on improvement of strength and ductility of fiber composite wrapped concrete.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

- The collaboration of CSUN and ATLSS will strengthen the research capability of CSUN faculty and students, and provide enriching experiences for underrepresented students.
- The data generated will be useful to users of steel in chloride environments. It may impact the future use of HSLA steels in these conditions.
- The data from the FRP-wrapped concrete will be useful to Caltrans and other users of this technology.

RESEARCH SUMMARY

TITLE: Fatigue Resistance of Cantilevered Sign Structures (ADC-E1)
TEAM LEADER: M.R. Kaczinski (CE), R.J. Dexter (Appl Mech)
TEAM MEMBERS: J. P. Van Dien (CE), B. Dechant (CE), J.W. Fisher (CE)

RESEARCH ISSUES ADDRESSED:

The project objective is to develop improved specifications that will result in fatigue-resistant designs of cantilevered signal, sign and light support structures.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address the key issue of Durability/Longevity of Infrastructure in the strategic plan. Proposed specification modifications will increase the reliability of sign support structures subject to wind-induced vibration and fatigue.

APPROACH; EXPERIMENTAL PLAN:

The loading of sign and support structures will be estimated from simplified models and from selected wind tunnel tests at the MIT Wright Brothers Laboratory. Transient and steady-state response of typical structures will be modelled using dynamic finite element analyses. The stiffness of the foundation and bolted base connection as well as the relationship between base forces and stress range on the anchor bolts will be determined experimentally and used in the analyses. Fatigue tests will be conducted to obtain an improved S-N Curve for the design of anchor bolts. Results of this investigation will be used to formulate simplified design guidance suitable for implementation in the AASHTO Specification.

RELATED WORK ELSEWHERE:

Related research on wind-induced vibration and fatigue was recently completed at the Michigan DOT Testing and Research Division. This work was primarily focused on in-situ structural monitoring of a test sign structure.

HOW ATLSS' WORK IS DIFFERENT:

A combined analytical and experimental approach has been developed to investigate this problem. The combination of wind tunnel testing, finite element analyses, experimental stress analysis and fatigue testing allow a full range of events to be simulated that might take a very long time to observe in-situ.

MILESTONES:

- Issue final report and design specifications, September 1995

DELIVERABLES:

Relevant information on wind-induced fatigue behavior of cantilevered sign structures can be used to propose changes to the existing AASHTO Specifications. Specific research results will include the identification and characterization of fatigue sensitive connection details, a rational method of determining wind loads on support structures and the constant amplitude fatigue limit of anchor bolts in axial tension will be identified.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Experts from state DOT's, consulting firms, and academia serve as project advisors for the National Cooperative Highway Research Program Agency.

RESEARCH SUMMARY

TITLE: Fatigue Criteria for Modular Bridge Expansion Joints (ADC-E3)
TEAM LEADER: M.R. Kaczinski (CE), R.J. Dexter (Appl Mech)
TEAM MEMBERS: J.W. Fisher (CE), R. Connor (CE)

RESEARCH ISSUES ADDRESSED:

The project objective is to develop performance-based specifications and commentary for the fatigue-resistant design of Modular Bridge expansion Joints (MBEJ).

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address the key issue of Durability/Longevity of Infrastructure highlighted in the strategic plan. Development of a design specification and recommended fatigue-testing acceptance procedures will increase the reliability of modular bridge expansion joints.

APPROACH; EXPERIMENTAL PLAN:

A comprehensive experimental and analytical program has been developed to investigate this problem. The field studies consisted of controlled static and dynamic tests to verify wheel load distribution among centerbeams, determine impact factors and the relationship between horizontal and vertical wheel loads. This information will be essential to develop a rational equivalent static load model. In addition, measurements taken under uncontrolled traffic loads will be used to determine stress range histogram results as critical details. The laboratory test program will be used to determine if the fatigue strength of MBEJ details are consistent with current fatigue resistance curves, evaluate differences between various manufacturers and models, and to provide guidance on the requirements which will be included in the proposed fatigue testing acceptance procedures.

RELATED WORK ELSEWHERE:

Related research on the fatigue behavior of modular bridge expansion joints has been conducted at the University of Washington and the University of Innsbruck. This work has focused primarily on the behavior of a single manufacturer's joint assembly and included laboratory testing of only isolated joint details.

HOW ATLSS' WORK IS DIFFERENT:

The ATLSS research program involves both field and laboratory tests on a wide variety of MBEJ systems to study this problem in a non-proprietary fashion. Field studies were conducted at four different MBEJ installations across the U.S. Laboratory tests, both static and dynamic, will also be performed on full-scale complete MBEJ assemblies and full-scale MBEJ sub-assemblies of the same joint types studied in the field. The laboratory tests will be conducted with load conditions which simulate field conditions.

MILESTONES:

- Conducted literature search and field studies at four locations, interim report - published March 1995.
- Began analytical and experimental program - January 1995.
- Issue final report - May 1996.

DELIVERABLES:

Relevant information on the loading characteristics, fatigue behavior, and durability of MBEJ will be used to develop design specifications and fatigue-testing acceptance procedures. Specific research results will include the development of a rational equivalent static load model, a reliable method to model these systems and perform structural analysis, and verification of the fatigue resistance of critical welded and bolted details.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Experts from state DOT's, consulting firms, and academia will serve as project advisors. The project is sponsored by the National Cooperative Highway Research Program (NCHRP Project 12-40).

RESEARCH SUMMARY

TITLE: Evaluation of Ductile Fracture Models for Ship Structural Details (IFC-E8)
TEAM LEADER: R.J. Dexter (Appl Mech)
TEAM MEMBERS: B.R. Somers (Mtl Sci), J.W. Fisher (CE), A.W. Pense (Mtl Sci), M.L. Gentilcore (ME)

RESEARCH ISSUES ADDRESSED:

Proven and reliable ductile fracture models, i.e. models to predict the behavior of cracked members fabricated from high-toughness steels, will allow the benefits of high-performance steel alloys (relative to less-expensive structural steel alloys) to be demonstrated.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

This project addresses the ATLSS "strategic objectives" of: 1) Improved Performance of New and Existing Structures, and; 2) Improved Maintainability and Repairability. The following ATLSS "key issues" were also addressed: 1) Knowledge Base on Large-Scale and/or Complete Structural Systems, and; 2) Connections and Structural Systems.

APPROACH; EXPERIMENTAL PLAN:

Ductile fracture models have been developed from tests of small simple specimens. None of these models have been shown to be directly applicable to full-scale welded members with complex geometry such as typical ship structure. In fact, there are known loading and geometry effects which will complicate the application to full-scale welded members. Full-scale specimens with typical ship structural details were fabricated from high-toughness steel and fatigue cracked by cyclic loading. These specimens are being tested to failure to obtain load, displacement, and crack extension histories. The limitations of the existing ductile fracture models will be determined and the models will be enhanced if necessary. Guidelines and commentary to facilitate the application of these ductile fracture models will be prepared.

RELATED WORK ELSEWHERE:

There have been numerous full-scale fracture experiments which have been studied in detail. All of these studies had specimens which were intended to represent thick sections typical of nuclear reactor pressure vessels. The International Atomic Energy Authority (IAEA) has sponsored an international project "FALSIRE" to verify fracture models with respect to these experiments. Ongoing joint research at Idaho National Engineering Laboratory (INEL) and MIT is focussing on developing improved fracture models.

HOW ATLSS' WORK IS DIFFERENT:

The ATLSS project is the first to focus on complex structural details fabricated from steel plate. Also, most of the previous work has involved steel with low or intermediate toughness which has resulted in cleavage or mixed ductile/cleavage fracture in the transition range. The ATLSS project focusses on high-toughness steel which will result in fully-plastic ductile behavior. This focus will lead to useful ductile fracture models at the end of the project.

MILESTONES:

This project began in July 1993. A project kickoff meeting was held 22 July 1993 at the ATLSS Center. A literature review and survey of ongoing research has been completed. The testing has been completed. The project will be completed by March 1996.

DELIVERABLES:

Quarterly reports are provided to the Ship Structure Committee. The final report will be issued in March 1996. The report will provide guidelines for the application of the selected ductile fracture model(s) as well as documentation of the research.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The project is sponsored by the Ship Structure Committee (Project SR-1349) which includes various American and Canadian government agencies as well as the American Bureau of Shipping. The project committee includes John Landes (University of Tennessee) and Walter Reuter (INEL). It is likely that the experiments will be studied as part of the joint INEL/MIT research project described above. Harold Reemsnyder from Homer Lab, Bethlehem Steel Corporation has attended meetings and taken an interest in the project. It is planned to have additional meetings at the ATLSS facility to review the work.

RESEARCH SUMMARY

TITLE: Smart Monitoring Systems for Large Structures (IMP-09)
TEAM LEADER: W-P. Li (EE)
TEAM MEMBERS: B.T. Yen (CE), Q. Cao (EE), F. Ling (EE), S. Segan (EE)

RESEARCH ISSUES ADDRESSED:

Current practice in inspection of structures requires experienced labor and expensive equipment, which subsequently leads to infrequent or no inspections of large structures. This project is to address this problem by using advanced signal processing techniques and VLSI technology.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

This project is a part of In-Service Monitoring and Control Technology research in ATLSS strategic plan. The goal of this project is to dramatically lower the cost of performing structure inspection and enhance the capability of monitoring and controlling the behavior of in-service structures.

APPROACH; EXPERIMENTAL PLAN:

A particular topic of fatigue damage monitoring has been chosen because fatigue damage assessment is an important issue in bridge inspection and evaluation. We have conceptualized an automated fatigue damage monitoring system which can be mounted on large structures. The algorithm used for fatigue damage estimation requires rainflow counting, stress histogram generation, and equivalent stress range calculation. Using calculated equivalent stress range and appropriate AASHTO fatigue design curves, the total number of fatigue cycles can be estimated. The remaining fatigue life of the monitored bridge member can be obtained by subtracting the number of used fatigue cycles from the total number of fatigue cycles. This project is to investigate the feasibility of implementing this algorithm by a VLSI chip, in order to collect and process data on site in real time. The next step is to study how to transmit processed data to a central facility through wireless channels.

RELATED WORK ELSEWHERE:

The research topics involved in this project include a signal processing algorithm, VLSI circuit design, fatigue data analysis, and large structure behavior. Many universities and companies have related research activities on these topics. However, traditionally, research on signal processing and VLSI design is in electrical engineering while research on fatigue data analysis and structure behavior is in civil engineering. Therefore, these topics are studied separately in those places.

HOW ATLSS' WORK IS DIFFERENT:

What is unique about this project at ATLSS is the fact that we have a cross-disciplinary team with faculty members and students in electrical engineering and civil engineering working together. The close interaction between the team members have greatly enhanced our understanding of the problems and the techniques to be used for solving them. The result of this project will significantly strengthen the capability of structure monitoring. The ATLSS facility is excellent for system testing.

MILESTONES:

Current Status:
- A front-end chip has been designed.
- An interface chip has been designed.
- A wireless data com. unit has been built.

Plan:
- Component testing: 5/1/95-8/31/95
- System integration: 9/1/95-12/31/95
- Technology transfer: 1/1/96-4/30/96

DELIVERABLES:

Knowledge-based Advances:
- Better understanding of structure behavior
- Knowledge-base for structural design
- Advanced signal processing and VLSI circuits

Technology-based Advances:
- New means of processing fatigue data
- Design of an integrated monitoring system
- More accurate assessment of large structures

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Wiss, Janney, Elstner Associates, Inc., has expressed interest in helping us evaluate our fatigue data processor in their Chicago field tests. Although the two initial attempts by their technicians were not conclusive, we have gained some firsthand experience in technology transfer. We will work with them more closely in every step of installation, operation, and data collection to ensure a meaningful evaluation of our system. We have established initial contact with Invocom Inc. which is a company working on a FHWA project for bridge instrumentation.

RESEARCH SUMMARY

TITLE: Smart Paint for Crack Sensing (IMP-12)
TEAM LEADER: R. Granata (Chem)
TEAM MEMBERS: J.W. Fisher (CE)

RESEARCH ISSUES ADDRESSED:

Method for facilitating routine inspections of structures for cracks and crack propagation. Development of data consistent with long-term designs, maintenance and planning. Existing inspection methods require unacceptably high sophistication or expertise level.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

In-Service Monitoring and Control Technology- Facilitate crack and high stress area detection by visual or chemically stimulated response in steel or concrete structures. Durability/Longevity of Infrastructure - Structural enhancement by early detection of cracks and high stress areas. Observers and non-experts can perform routine inspections.

APPROACH; EXPERIMENTAL PLAN:

The Smart Paint concept is a means to reveal cracks in a structural member by informal inspection. In this manner, inspections can be done more easily, from a greater distance and by less highly trained persons. The concept was developed as a paint material and initially demonstrated on fracture specimens, both steel and concrete materials. The paint functions by incorporation of dyes within microcapsules which fracture adjacent to a cracking structural member. Laboratory fracture tests have been successfully followed by laboratory fatigue tests. Both fatigue fractures and high stress deformation areas have been identified using Smart Paint. Experiments are on-going to develop a database for determining the utility of the coating material for in-service monitoring and control applications. Experiments included tests on compact tension specimens, large beams in transverse and longitudinal cracking modes, box beams specimens and attachment details including toe welds.

RELATED WORK ELSEWHERE:

There is no similar work known in-progress which takes this approach to the problem of making readily observable the structural cracks. Some earlier work had been done on less sophisticated coatings materials (brittle lacquer coatings), but none provided sufficient advantage over alternate assessment methods. Other types of evaluation methods are: 1) Application of Dye Penetrant; 2) Ultrasonic Tests; 3) Acoustic Emission; 4) Magnetic Particle Testing; 5) Eddy Current Imaging; 6) Radiography; and 7) Photoelastic Coatings.

HOW ATLSS' WORK IS DIFFERENT:

Advantages of Smart Paint over related technologies are: 1) Requirement of only one application for a permanent, in-place crack indicator (The competing technologies, other than close inspection, require the periodic use of measuring instruments which are not left in place.); 2) The detection of a crack in a substrate coated with Smart Paint can be done from a considerable distance (up to 15 feet depending on the observer's vision) by an observer with minimal training while instrumental methods depend on trained technicians.

MILESTONES:

1995-96: Determine detailed operating conditions for field use. Service (field) testing on fatigue specimens. Determine usefulness of Smart Paint as a high stress area indicator. Investigate utility as a means of showing crack patterns in concrete. Technology transfer.

DELIVERABLES:

(Conceptual & Technological advances). Structural members inspection is difficult - Task facilitation enables faster, more frequent inspections, use of less highly trained personnel and prospect of remote sensing by visual or fiber optical methods or, by chemical detection methods related to gas leak detection. Smart Paint provides structural inspection with a new approach to simplicity, ease-of-use and built-in inspection capability.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The main direct involvement is with Thies Technology, Inc., the supplier of microencapsulated material for this project's requirements. A number of others have expressed interest including Exxon, Physical Acoustics Corp., Naval Underwater Warfare Center, Bath Iron Works, Ingalls Shipbuilding. Full development of industry involvement is partially dependent on patent filing.

RESEARCH SUMMARY

TITLE: Development of Structure Load Sensor (IMP-15)
TEAM LEADER: R.D. Granata (Chem)
TEAM MEMBERS: B.T. Yen (CE), M. Moussavi-Madani (Phys),
W. Scott (Computer Interface Instrumentation)

RESEARCH ISSUES ADDRESSED:

To develop a durable piezoelectric load sensor for bridges and other structures. The sensor should measure load transferred directly through it and have use where compressive loads and, optionally, severe environments are present. Continuous monitoring is feasible for safety assessments and service life predictions.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

In-Service Monitoring and Control Technology - Facilitate direct detection of loads by electronic means in structures.

Durability/Longevity of Infrastructure - Structural enhancement and service management by detection of loads experienced during use.

APPROACH; EXPERIMENTAL PLAN:

Fabricate a device which senses load by measuring the changes in its own resonant frequency as it experiences compressive load. The device would consist of a thin polymeric piezoelectric transducer laminated between plates of an environmentally stable (corrosion and deformation resistant) structural material. When a harmonic (tuning) driving force of varying frequency is applied to such a device it will tend to have a maximum vibration amplitude at a wavelength that is an integer multiple of its thickness. Under compression, the load experienced by the device can be obtained by measuring the change in its resonant frequency as a result of reduction in its thickness. However, early results have indicated that phase shift is a more useful measurement. The initial development is planned towards a sensor with a capacity of about 10 kips.

RELATED WORK ELSEWHERE:

Considerable work is being pursued in the general area of piezoelectric transducers. However, no known activity is in-progress for transducers designed for use in large structural systems. Related work likely to positively affect this effort is underway at Rutgers University on the topic of polymer design for larger piezoelectric effects. Industrial efforts on piezoelectric transducers are pursued by Amp, Inc.

HOW ATLSS' WORK IS DIFFERENT:

Advantages of this transducer over related technologies (for example, strain gauges) are: 1) The total load is transferred through the measurement device. The device is likely to be more reliable because it measures load directly; 2) This technology may eventually result in zero-power load sensors compatible with low power IMP-09 Smart Monitoring Systems.

MILESTONES:

The work plan for this project consists of the following phases:

- 1995 Develop large-capacity sensors suitable for measuring significant structural loads.
- 1996 Implement sensors in structural applications in cooperation with industry/government.

DELIVERABLES:

(Conceptual & Technological advances).

A device is under development which will enhance the monitoring capabilities for structural systems. Methodologies for structure control and longevity are expected to benefit from this device.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The main direct involvement will likely be with Amp, Inc. for device development. Once the device proceeds to implementation phases, instrumentation and engineering companies will likely seek involvement. Technology transfer plans should be compatible with the ATLSS bridge-inspection activities.

RESEARCH SUMMARY

TITLE: Assessment of Remaining Capacity and Life of In-Service Structures (IMP-E1)
TEAM LEADER: J.W. Fisher (CE) and B.T. Yen (CE)
TEAM MEMBERS: Z. Ma (ME), E.J. Kaufmann (Mtl Sci), P. Xu (Mtl Sci)

RESEARCH ISSUES ADDRESSED:

The project objective is to aid the private and public sector in their analysis and evaluation of damage accumulation in existing steel structures by obtaining in-service response data and developing damage models and retrofit schemes. Studies are also made of defects and cracks to determine their cause.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address the key issues of durability and longevity of the infrastructure highlighted in the strategic plan. The project allows bridge and structural engineers to more accurately predict damage and provides verification and/or justification for retrofit decisions.

APPROACH; EXPERIMENTAL PLAN:

The project teams work cooperatively with industry partners and others as requested to obtain test data on bridge and other structures which are showing signs of distress such as cracking, unexpected deformations, and corrosion. Detailed failure analyses are frequently carried out on cracked elements through assessing material properties and causes of cracking.

RELATED WORK ELSEWHERE:

Similar experimental studies are being carried out throughout the world at:

- Swiss Federal Institute of Tech., Lausanne - Measuring the response of bridge structures for damage assessment.
- Tokyo Institute of Tech. - Evaluating cracking in steel bridges in Japan.
- University of Texas - Assisting Texas DOT with crack evaluation.
- University of Colorado - Measurements of bridge response.

HOW ATLSS' WORK IS DIFFERENT:

Project personnel have extensive experience and expertise in assessing the causes of fatigue cracking in steel bridges and developing retrofit procedures for correcting fatigue damage. They possess an extensive data base and experience with several hundred bridge structures and consider the total performance of the bridge structure. In addition, no other testing laboratory has the capability to carry out large scale variable load tests.

MILESTONES:

Assisted Weidlinger Assoc. and AEG-VonRoll in assessing the NDE procedures and implied discontinuities in the groove wells of the Newark Airport monorail structure. Assessed the results of ultrasonic and radiography testing. Acceptance criteria were developed. Assisting WJE with the failure evaluation of rigid frame joints that fractured during the Northridge Earthquake. Assisted NJ DOT on the failure of an inspection crane boom.

DELIVERABLES:

Experimental data from structural response and/or detailed failure analysis of crack segments removed from structures. Failure analysis of defects and cracks. Development of retrofit procedures.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

These studies are always initiated by industry (consultants or owners) in order to establish the causes of damage development and draw upon the project team's expertise in retrofitting and failure analysis.

RESEARCH SUMMARY

TITLE: Service Application of the Corrosion Coulometer (IMP-E3)
TEAM LEADER: R. Granata (Chem)
TEAM MEMBERS: A. Ettelman (Chem), P. Moquin (Chem), Bethlehem Steel (R. Wildt)

RESEARCH ISSUES ADDRESSED:

The corrosion coulometer provides a means of monitoring atmospheric corrosion processes of steel in natural or manmade environments for the purposes of competitive structure design and in-service assessment.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

In-Service Monitoring-Real-time monitoring of corrosive environment effects. Longevity - Infrastructure early warning device for excessive corrosion damage. Knowledge Base-Data for defining and modeling structural systems of metal durability to atmospheric exposure. System Design-Data for design considerations at specific constructions sites.

APPROACH; EXPERIMENTAL PLAN:

Measurements using coulometers under laboratory conditions verify responses in the field and provide determination of atmospheric corrosion mechanisms related to changing climatic/environmental conditions. Atmospheric corrosion measurements can be made in a real-time mode. This fundamental change in technology is enabled by the corrosion coulometer.

Applications include: Corrosivity appraisal of proposed construction sites for structure design and corrosion protection strategies, and; On-line monitoring of chemical plant facilities for changes in corrosivity conditions.

Significance: On-line monitoring of corrosion processes can be implemented comparable to corrosion monitoring in fluid chemical processes involving pipelines and storage tanks. The corrosion coulometer provides enhanced understanding of atmospheric corrosion processes.

RELATED WORK ELSEWHERE:

Electrochemical monitoring of steel atmospheric corrosion has been investigated by research groups headed by Mansfeld, Kucera, Agarwala and Sereda, also, commercially by Cormon, Ltd.

HOW ATLSS' WORK IS DIFFERENT:

None of the approaches pursued elsewhere have provided compact, simple and reliable implementation that can practically monitor structures in a realistic way. Most of the approaches depend upon very closely spaced galvanic couples and/or small-dimensioned parts. These designs are not likely to be adaptable to multiple-year studies for steel structures.

MILESTONES:

Accommodation of AISI and external funding interests - on-going.

Development and pursuit of proposals for transition of AISI work to provide an industry standard for Corrosion Coulometer use at bridge sites - 1995-1996.

Adaptation of the Corrosion Coulometer to non-bridge and non-steel structures - 1995-96.

DELIVERABLES:

(Conceptual & Technological advances).
Advances are Technology-based and include:

Appraisal of the corrosivity of a proposed construction site to assist in structure design and corrosion protection strategies, and;

On-line monitoring of chemical plant facilities for changes in corrosivity conditions. Both methodology and device creation would be accommodated as deliverables.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Individuals and organizations contribution advice, funding and cooperation:
BETHLEHEM STEEL--R. Wildt, R. Alpago, C. Gorman, H. Townsend, B. Droney; LUKENS STEEL--A. Wilson; AMERICAN IRON AND STEEL INSTITUTE--K. Almand; MICHIGAN DEPT OF TRANSPORTATION--R. Gould; PA DEPT OF TRANSPORTATION--J. Fulginiti; NEW JERSEY TURNPIKE AUTHORITY--H. Steinbeis; T.Y. LIN INTERNATIONAL--R. Lawrie; and Private (USX Corp.) funding of a corrosivity site study.

RESEARCH SUMMARY

TITLE: Assessment of Remaining Capacity and Life of Riveted Bridge Members (IMP-E6)
TEAM LEADER: J.W. Fisher (CE) and B.T. Yen (CE)
TEAM MEMBERS: Y. Zhou (CE), Z. Ma (ME), E.J. Kaufmann (Mtl Sci), D. Chen (Mtl Sci)

RESEARCH ISSUES ADDRESSED:

The objective is to develop and implement damage models for existing railroad bridges which are subjected to increasing car loadings. Very little variable amplitude experimental data exist on full scale riveted members, nor is it known what fatigue resistance curve should be used to assess damage. This study will provide that data base.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address the key issue of Durability/Longevity of Infrastructure highlighted in the strategic plan. This project will enable bridge engineers to more accurately assess damage accumulation in thousands of older bridges and can be expected to have a large impact on resource allocations.

APPROACH; EXPERIMENTAL PLAN:

The project has obtained full scale riveted bridge members from the Chicago Transit Authority and the Canadian National Railroad in order to carry out the necessary constant and variable amplitude fatigue testing. The project seeks to better define the constant amplitude fatigue limit as well as the fatigue resistance of girders subjected to stress range spectra simulating in-service structures. The experiment design seeks to obtain test data with effective stress ranges above and below the constant amplitude fatigue limit. It is essential to determine whether or not the damage model used for welded bridges is appropriate or too conservative.

RELATED WORK ELSEWHERE:

Research work in this area is being carried out at the:

- Swiss Federal Institute of Tech.-Lausanne, Variable amplitude experimental studies on riveted joints.
- University of Alberta - Constant amplitude experimental studies on riveted joints.
- University of Maryland/University of Pittsburgh - Variable amplitude studies on welded details.

HOW ATLSS' WORK IS DIFFERENT:

ATLSS experimental facilities permit full scale variable loading spectra to be tested on several beams at one time. Other variable load capabilities require small scale simulations. The interactions with our material science personnel allow us to explore whether or not prior damage existed and where cracks initiated.

MILESTONES:

Developed interim damage assessment models for AREA Committee 15 Steel Bridges specification provisions in cooperation with Dr. R.A.P. Sweeney, CN Rail. Adopted by AREA in 1992 .

Developed new resistance curves to assess fatigue damage in riveted members considering fabrication (punched vs drilled holes) and material. These curves were presented to AREA for consideration in Feb. 1995.

DELIVERABLES:

Completed all 18 full scale fatigue tests on riveted members. This included 10 tests under constant cycle loading at stress range levels between 6.2 and 11 ksi. Eight variable load tests were also completed yielding 16 fatigue test results.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

This study was initiated by industry (CN Rail) in 1990 as a result of their concern with damage assessment of many riveted bridges built at the beginning of the century. The economic demands for increasing loads mandate a solution. Industry has helped to define the load spectra, provided test specimens.

We have successfully assisted with the development of specification provision for rating bridges based on results to date. Revisions for extreme life calculations have been proposed.

RESEARCH SUMMARY

TITLE: Pseudo Dynamic Testing for Rigid Structural Specimens (EXP-03)
TEAM LEADER: Dr. Haluk Aktan (Wayne State University, CE), Dr. Le-Wu Lu (Lehigh University, CE)
TEAM MEMBERS: Wayne State: Victor Patton and Ayad Nayef (CE grad students),
Andrea Duff (CE undergrad)

RESEARCH ISSUES ADDRESSED:

The objective of this project was to develop and verify, both analytically and experimentally, the Pseudo-Dynamic procedure for the testing of rigid structural components. The intent was for a procedure with long-term applicability for testing scaled and full scale rigid buildings.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The strategic objective of this project was to provide a better understanding of seismic behavior of rigid structures, where the response characteristics are dominated by load path. The project also enhanced the educational and research programs for underrepresented students.

APPROACH; EXPERIMENTAL PLAN:

The goal was to develop the code and hardware interface such that the PDT procedure is transportable to ATLSS and other laboratories. The approach steps were:

1. Development of PDT software using FORTRAN. (Phase I)
2. Simulation of PDT procedure for method and software verification using a Ramberg-Osgood hysteresis model. (Phase I)
3. Development of data acquisition and control interface to the PDT software. (Phase II)
4. Tune and verify using single degree-of-freedom (Phases I and II) and three degree-of-freedom (Phase II) applications, using both force control and displacement control.

RELATED WORK ELSEWHERE:

PDT for flexible structures under unidirectional loads were developed and verified in Japan, Michigan and at U.C. Berkeley. ELSA (Italy) tested and improved a procedure for flexible structures using steel and RC specimens under linear elastic earthquake response.

HOW ATLSS' WORK IS DIFFERENT:

The PDT project at Wayne State described here was the development of a procedure for non-linear earthquake response of rigid buildings under unidirectional loads. The procedure developed here is unique and will allow testing of large buildings under simulated seismic loads, in contrast to testing specimens on vibration tables which can accommodate only small scale models.

MILESTONES:

- ATLSS Report No. 93-09 issued in June 1993 described the Phase I initial results from Wayne State.
- M.S. Theses were earned by Mr. Patton and Mr. Nayef.
- ATLSS Report No. 95-03 issued in January 1995 described the Phase II results, and concluded the project.

DELIVERABLES:

A PDT procedure that generalizes the applicability of the method to any structural system with real-time implementation potential. A transportable PDT procedure such that laboratories with appropriate facilities, like the ATLSS facility, can adopt it.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

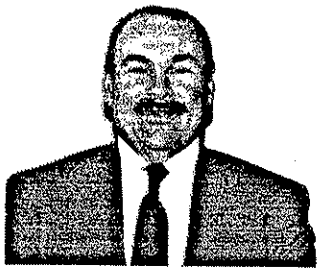
Poster presentations at ATLSS during NSF site visits provided the visitors with knowledge about the testing capabilities this procedure will provide.

The Phase I and Phase II reports were distributed to ATLSS industry partners.

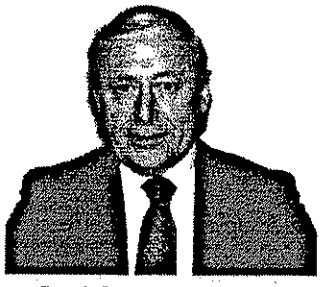
LIFE CYCLE ENGINEERING INFORMATION SYSTEMS

Thrust Leader

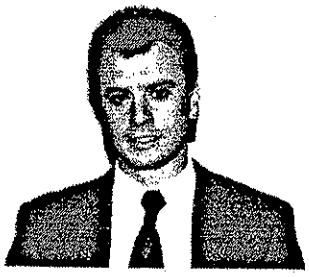
Prof. John Wilson
(CE)
(IMP-13, IFC-10, IFC-E9)



Prof. Frank Harvey
(Ed. Tech.)
(IMP-13)



Prof. Donald Hillman
(Comp. Sci.)
(IFC-10)

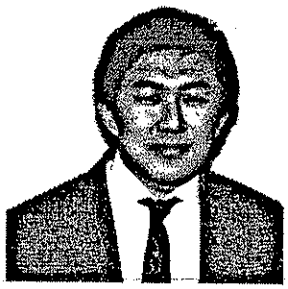


Prof. Richard Sause
(CE)
(ADC-08)

Prof. Ted Schlie
(Mgmt.)
(IFC-14)

Prof. Sarah Slaughter
(CE)
(ADC-11)

Prof. Bob Storer
(IE)
(IFC-12)



Prof. David Wu
(IE)
(IFC-12)

RESEARCH SUMMARY

TITLE: A Framework for Integrated Design (ADC-08)
TEAM LEADER: R. Sause (CE)
TEAM MEMBERS: C.H. Lee (CE)

RESEARCH ISSUES ADDRESSED:

The project objective is a framework of concepts for computer integrated systems that will include all structural design activities, support management of the activities, and manage information produced by the activities. The primary concepts are formal, integrated models for the design process and the design product (the facility).

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of the project address two key problem issues: Systems Methodology for Design, and Computer Integration of Design and Construction. The concepts developed by the project will contribute toward a systems methodology for design. Computer integrated design is a key step toward integrated design and construction.

APPROACH; EXPERIMENTAL PLAN:

The project builds on the Multilevel Selection-Development model of the structural design process. Improvements to the process model have been made, and product models have been developed for the information required and produced by design activities in the process model. Initially, the project focused on design activities and product descriptions in the preliminary design of steel frame structures. A prototype system for steel frame layout design, which demonstrates the models, was developed using object-oriented programming. The project developed object-oriented concepts for structural analysis within an integrated system, and several practical structural design case studies. The current focus is on more formal concepts, notation, and techniques for representing integrated models, and on developing a comprehensive, integrated process and product model for building frame design. The project draws on theory and programming techniques from areas of Computer Science including artificial intelligence, object-oriented programming and databases.

RELATED WORK ELSEWHERE:

Related research is ongoing at EDRC (Carnegie Mellon Univ.), CIFE (Stanford Univ.), the Univ. of Massachusetts, Pennsylvania State University, and the Univ. of Florida. The related work is in: (1) product models based on advanced geometric models (EDRC), hierarchical modeling concepts for data exchange (CIFE), and the concept of "features" (Massachusetts and Florida); and (2) process models for design (EDRC and Massachusetts) and for the planning, design and construction process (Penn State).

HOW ATLSS' WORK IS DIFFERENT:

The concept of integrated process and product models distinguishes this project from related work. Design process and product models are integrated into a single unit. Each activity is in the process model, and each entity in the product model describes information needed or produced by activities in the process model. ATLSS' work develops and uses new notation to represent the design process, the design product, and the relationship between them.

MILESTONES:

- Report on Integrated modeling concepts and techniques - Aug. 1994.
- Report on integrated process and product model for building frame design - Dec. 1995.

DELIVERABLES:

The project will develop integrated process and product models for structural design including concepts and techniques for developing integrated models, and a comprehensive integrated model for building frame design. The models are intended to be a theoretical contribution toward future integrated computer-aided design systems. The end users of these concepts re the commercial developers of these systems, and the engineers that use them.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

An advisory panel composed of practicing engineers and software developers was organized during the 1991-92 year. The project was presented to an industry panel in May 1992, and was well-received. During 1992-93, the project worked with industry to develop case studies that demonstrate the structural design process used in current practice. The project will work with industry to test and validate the models that are developed.

RESEARCH SUMMARY

TITLE: Economic Assessment of the ATLSS Integrated Building System (ADC-11)
TEAM LEADER: E.S. Slaughter (CE)
TEAM MEMBERS: M. Eraso (CE); R. Hendricks, B. Thomas, P. Patel (DuPont)

RESEARCH ISSUES ADDRESSED:

The project objectives are to assess the economic impact of integrated building systems, including one that incorporates an ATLSS connection and the Stewart platform erection system, and to develop a methodology for the systematic comparison and evaluation of different building systems.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The key problem areas for this research are the Systems Methodology for Design, and the Knowledge Base on Large Scale/Complete Structural Systems. This research will provide a better understanding of the technical, and economic aspects of the design, fabrication, erection and decommissioning of integrated building systems.

APPROACH; EXPERIMENTAL PLAN:

The research will assess the potential benefits, opportunities, and costs of an integrated building system with respect to two different bases: current practice; and technologies that either currently under development or are forecasted to appear in the near term. The research program of the project consists of 4 stages: 1) assess the state-of-the-art in construction automation, robotics, and other related technologies; 2) evaluate the opportunities and costs of the ATLSS Integrated Building System compared with current methods of design, fabrication, and erection; 3) develop a methodology for the systematic comparison and evaluation of different building systems; and 4) develop and conduct computer simulations which will include critical influence factors and aid the economic assessment of integrated building systems using either ATLSS or competitive technologies.

RELATED WORK ELSEWHERE:

While NIST, CMU and a few other universities are developing Integrated Building Systems, none are conducting detailed economic assessments of the feasibility of these systems or computer simulation models. Related work in the methodology development of engineering economic analysis of flexible manufacturing systems is being conducted at BU, Purdue, CUNY, and UC Berkeley.

HOW ATLSS' WORK IS DIFFERENT:

While all of the other economic assessment work on flexible manufacturing systems uses distant or *ex post facto* information, this research is being conducted in parallel with the technology development, and therefore can influence the direction and applicability of the final technology form. In addition, this is the only project that assesses the economic impact of automatic/remote controlled technology applied to construction.

MILESTONES:

- ATLSS REPORT 93-15 on the state of the art in related automation technologies.
- Functioning simulation models (structural steel erection)-October 1994.
- ATLSS REPORT 94-16 describing simulation models on opportunities for integrated building systems.
- FINAL REPORT with summary of results for integrated building systems and other advanced construction technologies-May 1995.

DELIVERABLES:

An up-to-date assessment of the application of advanced automation and remote-control technologies to the construction industry, a methodology for assessing the economic impact of different advanced building systems, computer-based simulation models, and a specific application of the models to the ATLSS connection and Stewart Platform. Intended users are structural designers, fabricators, erectors, and owners of facilities.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

An industry advisory panel was initiated consisting of representatives of engineering design firms, steel fabricators, erectors, labor organizations, and owners of constructed facilities; Direct involvement of firms in base case cost analyses, in-depth interviews on cost analyses for existing, developing, and ATLSS technologies, and verification of simulation models and previously collected cost estimates; A commercialization plan for this system is under development with Competitive Technologies Inc.

RESEARCH SUMMARY

TITLE: Cooperative Building Design Network (CBDN) (IFC-10)
TEAM LEADER: J.L. Wilson (CE), D.J. Hillman (Comp. Sci)
TEAM MEMBERS: S.J. Wagaman (Comp. Sci), C.G. Shi (CE), G. Baek (Comp. Sci), J. Liu (CE)

RESEARCH ISSUES ADDRESSED:

The goals are to help alleviate information flow problems and promote cooperative problem-solving among participants in the construction process. CBDN is a distributed KBS that permits users to exchange knowledge during preliminary design of beam-to-column connections, resulting in reduction of costly delays and field rework.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address the key issue of Computer Integration of Design and Construction in the strategic plan. Use of this system will help improve the information flow among participants in the design/construct process.

APPROACH; EXPERIMENTAL PLAN:

A CBDN prototype was developed to support cooperation in a distributed problem-solving environment. This prototype is organized as several Knowledge-Based Systems (KBS), each of which represents the particular knowledge of a designer, fabricator, and erector.

CBDN is a multiple-stage system, which solves a problem by decomposing it into smaller sub-problems. At each sub-problem stage, the partial solution is represented as a ranked set of alternatives resulting from the collection of individual choices. Communication among the participants facilitates a collective solution of the entire problem of preliminary design of beam-to-column steel connections. Consensus among the participants is achieved through extensive dialogue and information exchange.

RELATED WORK ELSEWHERE:

Related research in knowledge based systems for structural evaluation includes: a) Carnegie-Mellon University b) Integrated Building Design Environment (IBDE); Engineering Design Research Center (MIT), c) Center for Construction Research and Education (CCRE) d) Pennsylvania State University - Information Architectures for Construction e) Stanford University - Center for Integrated Facility Engineering (CIFE) f) Research on computer supported cooperative work at several universities.

HOW ATLSS' WORK IS DIFFERENT:

CBDN is a distributed knowledge based system accounting for the various aspects of the preliminary design process. The horizontal integration and cooperative problem-solving process at a particular level of design (preliminary design) separates CBDN from other more vertical systems dealing with the entire design process from a unique perspective. The focus of the project is on cooperation through dialogue and information exchange to bridge the gap between the participants of the construction process.

MILESTONES:

· Conversion of the existing model of connection knowledge to a generic form capable of handling additional construction knowledge - August 1995.
· Development of a graphical user interface (GUI) for PCs - December 1995.
· Development of a multimedia prototype - May 1996.

DELIVERABLES:

Development of a conceptual model for a design support environment.

Development of a computational model and implementation of an initial prototype system to form an application testbed and demonstration vehicle.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

• STV/Seelye Stevenson Value & Knecht: Ira Hooper continued to provide advice on strategic issues for cooperative problem-solving;
• Iffland, Kavanagh, Waterbury, P.C.: Avanti Shroff met with the Lehigh group to discuss multi-media approaches to problem-solving.

RESEARCH SUMMARY

TITLE: Planning, Scheduling, and Coordination of Construction Activities (IFC-12)
TEAM LEADER: S.D. Wu (IE), R.H. Storer (IE)
TEAM MEMBERS: K. Naphade (IE)

RESEARCH ISSUES ADDRESSED:

The objective was to address the computational and the practical aspects of construction planning and scheduling and to develop and successfully test new models and computational techniques on construction scheduling problems subject to resource, space and material restrictions.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The models and algorithms developed, and more recent work in the generation of efficient construction erection sequences, will contribute to development of computer-aided construction management, and bolster ATLSS' impact in this area.

APPROACH; EXPERIMENTAL PLAN:

Currently used decision support systems in construction planning and scheduling either ignore, or give short shrift to issues of limited resources and temporal uncertainty. New approaches to these problems have been developed, coded, and tested successfully.

Based on test results on real world construction problems, it became clear that erection sequences are typically decided by engineers and embedded in the project precedence network. While some of these constraints are necessary due to physical or practical constraints, many other constraints included in the networks are made unnecessarily and arbitrarily. Developing ways to use computational methods to generate efficient assembly sequences and then schedules is significant in that it brings sophisticated planning tools into the process earlier and thus has the potential for greater impact.

RELATED WORK ELSEWHERE:

Past research at Lehigh, some funded by NSF, in production planning and control has successfully addressed many of the same issues in the context of manufacturing systems. this study adapted the work in manufacturing to the construction industry.

HOW ATLSS' WORK IS DIFFERENT:

Manufacturing scheduling and construction scheduling are quite similar problems. However, once practical constraints are taken into account, the underlying mathematical models start to deviate. For example, in manufacturing firms, the space and the contractual restrictions are typically insignificant, but they are critical in construction projects. Recognizing these differences, we have adapted our base methods to construction management. These method will be tested on real construction scheduling problems.

MILESTONES:

This project was completed, and was reported in ATLSS report No. 94-03.

DELIVERABLES:

- Verified test results on industrial test problems, and identified additional key areas in which our research can impact construction productivity.
- A strong proposal for additional funding to continue the project, addressing the new topic of efficient erection sequences. CII and US Army Corps of Engineers are potential funding sources.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

In conjunction with Prof. S. Slaughter, we have contacted the CERL research labs in regard to possible funding and collaboration. We have visited BE&K in Newark Delaware and had a very worthwhile discussion about the scheduling problems they face. As a result of the visit, we are provided test problems from some of their large construction projects. We have initiated similar contact with Butz and Bechtel. At the spring ATLSS meeting, we have presented our work to date to a group of industry representatives from Bechtel, BE&K, Butz, Primavera, etc.

RESEARCH SUMMARY

TITLE: Global Technology Sourcing for U.S. Construction Industry (IFC-14)
TEAM LEADER: T.W. Schlie (Mgmt)
TEAM MEMBERS: S.R. Roth (Mgmt), D.A. Veshosky (CE, Lafayette College)

RESEARCH ISSUES ADDRESSED:

U.S. construction industry competitiveness, particularly regarding acquisition and diffusion of construction technology and effectiveness of external technology sourcing.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

Supports the strategic objective of improving construction automation and adoption of innovative technology to enhance competitiveness.

APPROACH; EXPERIMENTAL PLAN:

There are three primary phases of this exploratory study: 1) literature review and summary, 2) design and execution of survey, and 3) analysis of survey results. The survey will address the level of effort, organizational positioning, and effectiveness of external technology sourcing in the U.S. construction industry.

RELATED WORK ELSEWHERE:

Discussion with organizations likely to perform similar research has led us to believe that this work does not duplicate efforts elsewhere.

HOW ATLSS' WORK IS DIFFERENT:

There is no known related or similar work to which this project is comparable.

MILESTONES:

Literature review and analysis complete 7 Jan. 94, interviews from 11 Feb. to 26 May, feasibility report and analysis from 6 May to 31 Aug. (completion of project).

Project completed Aug. '94.

DELIVERABLES:

Bibliography, interview and results, feasibility report containing technology sourcing activity descriptions, management and organizational variables.

Follow on case studies in Phase II-approval granted by Foster-Wheeler (Feb. '95).

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Report sent to 28 companies that participated in the study. Follow-up discussions with Foster-Wheeler about the results and additional case studies development.

RESEARCH SUMMARY

TITLE: Integration of Life-cycle Analysis into Project Design and Construction (IFC-E9)
TEAM LEADER: J. Wilson (CE)
TEAM MEMBERS: P. Bryan (CE)

RESEARCH ISSUES ADDRESSED:

Develop a useful methodology, consisting of models, processes, and tools, for identifying and incorporating life-cycle considerations into facility design, operation and renewal decisions.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

This highly cross-disciplinary project addresses the key technological barrier of the lack of the comprehensive models of life-cycle performance and cost models.

APPROACH; EXPERIMENTAL PLAN:

The research will identify and systematize specific engineering decisions which significantly affect the performance and cost of selected facility types such as buildings and process plants over their life. Issues across design, construction, and maintenance will be addressed. The methodology will provide a feedback mechanism which addresses changes and modifications during the life-cycle process that will affect cost and performance. Checklists will be incorporated into the methodology to help provide a standard for identifying and evaluating life-cycle factors. An inventory of data sources and current life-cycle practices will be compiled from site visits and interviews with task force member companies. The life-cycle models will be validated on selected test cases. Regulatory issues, safety and environmental, will affect implementation and must be addressed.

RELATED WORK ELSEWHERE:

A few universities, government agencies, and major corporations have studies life-cycle cost calculation methods. While consideration of life-cycle costs is generally considered worthwhile, methods for life-cycle engineering are not well developed and are currently inadequate.

HOW ATLSS' WORK IS DIFFERENT:

This research will address life-cycle engineering as a combination of decisions made throughout the life of the facility. It will include major engineering decisions as well as cost models.

MILESTONES:

- Identify key life-cycle phases, factors for performance and costs by Sept. 1995.
- Generalized life-cycle cost models for buildings and process plants by Feb. 1996.
- Decision tables by Jul. 1996.
- Supplemental checklists by Sept. 1996.
- PC Software to support cost models and decision tables by Mar. 1997.
- Validation on a test case by Jul. 1997.

DELIVERABLES:

- Decision Models
- Decision Tables
- Life-cycle Cost Formulas
- Checklists
- Demonstration Prototype
- Self-evaluation Tool

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

John Brown Inc.
M K Corp.
TPA Inc.
U.S. Army Corps of Engineers
Belcan Inc.
Phillips Petroleum Inc.
Turner Inc.
U.S. Dept. of State
Eli Lilly & Company
James River
Union Carbide

RESEARCH SUMMARY

TITLE: Advanced Information Systems for Bridge Evaluation (IMP-13)
TEAM LEADER: F.A. Harvey (Ed. Tech), J.L. Wilson (CE)
TEAM MEMBERS: S.J. Wagaman (Comp. Sci.), G.E. Sadavage (Ed. Tech.)

RESEARCH ISSUES ADDRESSED:

The project objective is to develop and implement a hypermedia application to support training and technology transfer of the Bridge Fatigue Investigator (BFI) to inspectors and engineers. BFI is a knowledge-based system that assists in the fatigue evaluation of steel bridges.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this project address the key issue of Durability/Longevity of Infrastructure in the strategic plan. This system will enable practitioners to perform bridge evaluations more effectively and reliably.

APPROACH; EXPERIMENTAL PLAN:

A BFI hypermedia system (H-BFI) is being designed to support training of and technology transfer to bridge inspectors and engineers. Hypermedia technology integrates diverse elements such as text, graphics, audio, and full motion video on a single computer system. The system is designed in a way which allows users to access, use, and interrelate a large amount of information easily and efficiently.

The current hypermedia system (pre-inspection) consists of a series of prompts to the user on bridge detail and geometry, an evaluation based on the bridge detail, and a report to the user with the locations of fatigue critical areas. In H-BFI, users can select areas of the bridge to virtually explore for fatigue damage and immediately receive feedback on their inspection skills.

RELATED WORK ELSEWHERE:

Related research in knowledge based systems for structural evaluation includes:

- NIST — Concrete Evaluation
- FHWA — Bridge Evaluation
- Kansas State Univ. on Bridge Evaluation

General work on applied artificial intelligence at numerous universities. Research and development of multimedia applications for engineering education through the Synthesis and other NSF Engineering Education Coalitions.

HOW ATLSS' WORK IS DIFFERENT:

BFI is an extensive knowledge base which contains detailed information on 206 bridges and the fatigue knowledge related to bridge detail. The knowledge base is constructed using an open architecture, which allows for enhancing and extending the KBS.

In order to enhance comprehension of computer-based information, a process model for the design and implementation of an integrated hypermedia training system has been developed and implemented.

MILESTONES:

(a) Validation/Verification of Knowledge Base by Fatigue Experts - 11/94. (b) Completion of Hypermedia System with Full BFI Simulation - 5/94. (c) Beta Site Testing by DOT's and Consulting Firms - 1/94-6/95. (d) Demonstration to FHWA - 6/95. (e) Production Version of KBS Available in Visual C++ - 9/95.

DELIVERABLES:

A new computer-based tool using hypermedia, analytical methods, and knowledge-based systems for the fatigue inspection and evaluation of steel bridges. The intended users are bridge inspectors and engineers associated with FHWA, AASHTO, individual state DOT's and engineering firms that do bridge inspection. This system is expected to be incorporated into FHWA and AASHTO training methods.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

Presentation to AASHTO technical subcommittee on bridges. Ongoing work with Bettigole, Andrews & Clark, (Inc.). Presentation to ASCE Structures Congress '95. Numerous demos and interactions with state and federal agencies. HBFI Workshop to state DOT's and other consulting agencies. A commercialization plan is under development with Competitive Technologies (Inc.) . Planned incorporation into FHWA training course. Interactions with Iffland, Kavanaugh, Waterbury (IIBIS).

SEISMIC RESEARCH PROGRAM

Program Leader

Prof. Le Wu Lu
(CE)
(SRP-E1)

Prof. John Fisher
(CE)
(SRP-E1, SRP-E4, SRP-E5)

Dr. Eric Kaufmann
(Matls. Sci.)
(SRP-E1, SRP-E4, SRP-E5)

Prof. James Ricles
(CE)
(SRP-E3)

Prof. Richard Sause
(CE)
(SRP-E2)

RESEARCH SUMMARY

TITLE: Ductility Enhancement of Steel Beam-to-Column Connections (SRP-E1)
TEAM LEADER: L.W. Lu (CE), J.W. Fisher (CE), E.J. Kaufmann (Mtl Sci)
TEAM MEMBERS: M. Xue (CE)

RESEARCH ISSUES ADDRESSED:

The objective is to 1) determine the probable causes of cracking of steel beam-to-column connections as experienced during the Northridge earthquake, 2) evaluate the adequacy of repair methods, 3) fund cost-effective ways to improve connection performance & 4) develop reliable design & fabrication procedures for welded connections.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals address the key issues of performance and durability of building infrastructure. The project will enable designers and contractors to more accurately assess damage potential of existing infrastructure as well as the reliability of repair procedures.

APPROACH; EXPERIMENTAL PLAN:

The project will examine the welding procedure and quality of weld metal and especially adequate levels of fracture toughness of the repairs and existing welds. Full scale dynamic experiments will be carried out on prototype beam-to-column connections and on repaired connections. Dynamic experiments on modified connections with enhanced ductility will be examined. The experiments will examine strain rates comparable to those observed at Northridge.

RELATED WORK ELSEWHERE:

The SAC research program involves primarily static tests on similar joints at Texas, U.C. Berkeley, U.C. San Diego and EERC. Some smaller scale dynamic tests are planned at U.C. San Diego.

HOW ATLSS' WORK IS DIFFERENT:

ATLSS experimental facilities permit full scale dynamic loading capable for simulating the strain rates experienced in the field. The interaction of structural and materials science engineers allows us to explore facets of performance that others have limited experience with.

MILESTONES:

Complete eight large-size connections test subjected to cyclically applied dynamic load to ascertain cracking causes and role of weld metal toughness. Complete eight tests to evaluate modifications to protect connections and enhance beam ductility. The repair methods examined will include the three AISC guideline recommendations.

DELIVERABLES:

Studies of welding procedure and quality of weld metal. Dynamic experiments on eight large-size connections in the as-frabicated and repaired conditions. Dynamic experiments on modified connections with enhanced ductility and lower connection demand. Non-linear FEM studies to evaluate strain and deformation in critical regions. Recommendations on design, repair, fabrication and assembly.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

This study will be a contribution to the variables and studies of beam-column connections that are necessary to understand and repair connections in damaged Northridge structures. The results will be shared with SAC and all interested industry.

This work is co-sponsored by the Institute of the Ironworking Industry and the California Field Ironworkers. Coordination with AISC and AISI is part of the technology transfer effort.

RESEARCH SUMMARY

TITLE: Performance of Precast Parking Garages; Influence of Diaphragms (SRP-E2)
TEAM LEADER: R. Sause (CE)
TEAM MEMBERS: S.P. Pessiki (CE), R.B. Fleischman (CE), A. Rhodes (CE)

RESEARCH ISSUES ADDRESSED:

Some precast parking structures performed poorly in the Northridge CA earthquake, including several collapses. Possible causes of the failures include the unusually high vertical acceleration, unaccounted diaphragm flexibility, and insufficient load path between the gravity system and the lateral system. This research addresses the latter two.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

Improved performance of existing structures; new structural systems.

APPROACH; EXPERIMENTAL PLAN:

The research combines analysis with forensic observations. The research examines the effect of ground motion on the parking structures in the transverse and longitudinal directions separately. The analyses fall under two major categories: nonlinear static analyses of individual diaphragms or shear walls to develop stiffness and strength values for these components; and nonlinear transient dynamic analyses of the full structure using the stiffness and strength values previously obtained. The static analyses are performed with an increasing level of sophistication: elastic analyses are performed to determine high stress regions and general deflected shapes; coarse mesh inelastic analyses are then performed to determine potential locations of concrete cracking; finally, meshes with inter-panel separation models in the critical regions are analyzed. These models included chord steel pullout and brittle wire-mesh response. The dynamic analyses involve a complex multi-degree-of-freedom model including the effect of intra-floor ramp response.

RELATED WORK ELSEWHERE:

Presently related research is being performed at Univ. of Illinois, Univ. of Washington, and within engineering firms in Los Angeles. The Illinois work focuses on examining force paths through the structure. The Washington work examines diaphragm flexibility. The work done in Los Angeles deals primarily with forensics and examining the adequacy of the strength designs with respect to large vertical acceleration.

HOW ATLSS' WORK IS DIFFERENT:

Much of the problem with the parking garages may originate in the manner in which the design process occurs. The gravity system is designed by the precast company; the lateral system by the design engineer of record. Because of the dichotomy in design, simplifying assumptions are made to relate the two systems including an assumption of rigid diaphragm and an equilibrium based force transfer design. The first simplification may severely underestimate deformation demand on the gravity system; the second may underestimate force demand.

MILESTONES:

In the seven months since the project was initiated, a qualitative understanding of the system behavior has been reached. The static stiffness and strength values have been determined for the transverse direction for a variety of floor configurations and system-related boundary conditions. Bounding values have been determined for the longitudinal direction along with a study of the ramp force input to the diaphragm. The project will be completed by August 1995.

DELIVERABLES:

The goals of the project are to (a) provide information on the system behavior of parking structures, (b) establish design and detailing guidelines for parking garage diaphragms in seismic regions, (c) determine the gravity system deformation demand due to flexible diaphragms, (d) determine the force paths involved in the transfer of the inertial forces from the diaphragm to the shear walls.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The prototype structure for the project was designed by Englekirk and Nakaki, Inc., a structural consulting firm with extensive experience in the design of parking structures and the seismic performance of structures. Frequent phone conversations are held between team members and the consultants. The work was presented at a CURE meeting in CA in Dec. 1994 and at PCI Committee Days in Chicago in Apr. 1995.

RESEARCH SUMMARY

TITLE: Seismic Performance of Concrete Filled Tubular Column-To-Wide Flange Beam Moment Connections (SRP-E3)
TEAM LEADER: J.M. Ricles (CE)
TEAM MEMBERS: L.W. Lu (CE), T.K. Sooi (CE), G. Vermaas (CE), W. Graham (CE)

RESEARCH ISSUES ADDRESSED:

Objectives: (1) to assess the force transfer mechanism, and the effect of various connection details in moment connections for concrete filled tube (CFT) column-to-wide flange (WF) beam framing systems under seismic loading, and (2) develop feasible connection details and capacity design equations.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The objective of the study and the deliverables fits the ERC's strategic objective in the areas of innovative structural systems and materials as well as improved performance of new and existing structures.

APPROACH; EXPERIMENTAL PLAN:

The study involves both analytical and experimental investigations. The analytical investigations will determine stiffness and strength requirements, and ductility demands imposed on CFT column-to-WF beam lateral load resisting systems during an earthquake. Inelastic time history analysis are being conducted, where generic CFT column system frames of various heights are being modeled. The results from these analyses will provide information on the demand and requirements during an earthquake, and how these are affected by a building's geometry as well as structural member proportions and connection stiffness. Inelastic time history analysis results are to be incorporated into subsequent detailed nonlinear finite element analyses, modeling the local regions of the connection in order to assess the local force transfer mechanism and determine how this mechanism is affected by various connection details. The experimental program involves the testing of full scale connection assemblages under seismic loading.

RELATED WORK ELSEWHERE:

Research related to connection behavior for CFT columns systems has been conducted in Japan, Europe; Australia, as well as in the United States. A majority of this work is small-scale, and is not all related to moment connections. Some of this work involves seismic loading conditions.

HOW ATLSS' WORK IS DIFFERENT:

The work being pursued at ATLSS involves full scale testing and analysis for seismic loading conditions. The ATLSS study will involve using high strength and performance steel and concrete materials. In addition, connection details are being investigated at ATLSS which omit interior diaphragms as well as address the issue of semi-rigid connections.

MILESTONES:

(1) CFT tube panel zone tests were completed in August, 1994 which verified an analytical model for predicting the capacity of the panel zone. (2) A generic CFT column-WF beam frame system has been deigned, and is currently being analyzed for evaluating demand imposed on the connections due to seismic loading. (3) The test frame for the full scale experimental test program has been designed and erected, and testing is to commence in May 1995.

DELIVERABLES:

Information on the performance of these types of connections involving the use of conventional and high performance materials under seismic loading. Recommendations for connection details that are practical to fabricate and have good performance. Design equations based on the "Truss Model" are for use by practicing engineers in determining the capacity of the panel zone of these connections.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

The project has resulted in interaction between the research team and various fabricators, practicing engineers, and consultants, who have provided advise. Papers related to the progress of research have been presented at the 1995 SSRC Conference in Kansas City, Missouri, as well as the Third International Steel Conference in Trento, Italy.

RESEARCH SUMMARY

TITLE: Use of Simulation Specimens in Studies of Fractures and Failures in Buildings (SRP-E4)
TEAM LEADER: E.J. Kaufmann (Mtl Sci), J.W. Fisher (CE)
TEAM MEMBERS: R.J. Dexter (CE & Mech), P. Xu (Mtl Sci)

RESEARCH ISSUES ADDRESSED:
The objectives are: (1) To prepare a state-of-art paper on fracture of welded connections; (2) To fabricate and test simulated groove welded beam-column tension flange connections for fracture behavior and repair procedures; (3) To evaluate the fractures that occur in beam-column tests. This study is part of the SAC-Phase I Program.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:
The goals of this study address key issues of durability, repairability and performance of existing infrastructure with welded beam-column connections. This project will enable engineers to understand the root causes of premature failures, and provide rational means to correct the deficiencies.

APPROACH; EXPERIMENTAL PLAN:
The project will examine a variety of variables such as loading rate, weld metal properties, base metal properties, weld repair, and geometry. The tests will be carried out in two phases to ensure that the specimen adequately simulates the beam tension flange. Cyclic loads will be applied at 1 to 2 Hz loading frequency. In addition to the experimental work on the simulated weld joint, failure analyses of fractures will also be conducted on beam-column tests carried out by others on the SAC program.

RELATED WORK ELSEWHERE:
Research work in this area is being carried out at the SAC supported universities including: (a) U.C.-Berkeley - static tests on large scale beam-column connections; (b) U.C.-San Diego - dynamic tests on medium scale beam-column connections, and (c) Univ. of Texas - static tests on large scale beam-column connections.
These studies include as-welded joints simulating pre-Northridge practice as well as changes to improve the welds and remove backing bars, and examination of repair procedures.

HOW ATLSS' WORK IS DIFFERENT:
ATLSS has more dynamic capability to examine loading rates. In addition, its interdisciplinary team is uniquely qualified for failure analyses as a result of several decades of studies on the fatigue and fracture behavior of welded connections in the laboratory as well as in the field.

MILESTONES:
- Prepare a state-of-art report on fracture behavior of welded joints and the fracture mechanics of structural steel.
- Complete Phase I tests to ascertain effectiveness of joint simulation.
- If successful proceed to Phase II.
- Evaluate fracture surfaces of SAC beam-column fractures and establish crack initiation.

DELIVERABLES:
- Complete 15 tests of simulated beam-column tension flange tests.
- Complete state-of-the-art report on fracture mechanics application to joint fracture.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:
This study was initiated by SAC to provide the interdisciplinary assessment of connection fracture. The understanding will assist in solution of retrofitting existing beam-column connections as well as an understanding of the causes of their fracture.

RESEARCH SUMMARY

TITLE: Failure analysis of Damages in Building Structures (SRP-E5)
TEAM LEADER: J.W. Fisher (CE), E.J. Kaufmann (Mtl Sci)
TEAM MEMBERS: R.J. Dexter (Mech), P. Xu (Mtl Sci)

RESEARCH ISSUES ADDRESSED:

Most of the assessment and evaluation of connection failures at Northridge have focused on the external fracture path appearance and have not focused on detailed fracture analysis of the cracked components. This study will detail and evaluate the cause of fracture in order to explain the various types of cracking observed.

RELATIONSHIP TO ATLSS' STRATEGIC PLAN:

The goals of this study address the key issues of life prediction and condition assessment including theoretical modeling of deterioration.

APPROACH; EXPERIMENTAL PLAN:

The project seeks to arrange for acquisition of failed sections of beam-column connections from at least five buildings including a variety of column and beam sizes and fracture types. Stress levels will be estimated by John A. Martin Associates and CSUN using response spectrum from ground motion records. The material properties will be characterized by appropriate tests. Welds will be examined for weld process, parameters, discontinuities. Fractographic examinations will be performed to identify and characterize the fracture origin and fracture mechanism. Fracture mechanics methodologies will be used to relate the observations, stress levels, and material characteristics.

RELATED WORK ELSEWHERE:

Limited material testing is being carried out by Twining Laboratories and Smith-Emery Laboratory. No other detailed fractographic evaluations and failure analyses are being carried out that are known.

HOW ATLSS' WORK IS DIFFERENT:

The ATLSS experience in failure analysis of bridge structures subjected to fatigue and fracture is being utilized as well as the interdisciplinary work in materials, welding and failure evaluations.

MILESTONES:

- Identify candidate buildings with cracked connections with consultant assistance.
- Arrange for several cracked joints to be removed for evaluation.
- Carry out metallographic and fractographic studies of fractures.
- Assistance with material properties from Twining, Smith-Emery, and CSUN.

DELIVERABLES:

Fracture analysis of failed connections to identify cause of fracture initiation and role of materials. Preparation of a report that documents the findings and conclusions of the study.

INDUSTRY INTERACTION & TECHNOLOGY TRANSFER ACCOMPLISHMENTS:

This study will involve engineering firms and test laboratories involved with inspection, assessment and repair of damaged members.